University of Alberta

Recovery of Bird and Amphibian Assemblages in Restored Wetlands in Prairie Canada

By

Allison Jane Puchniak

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of the requirements for the degree of Master of Science

in

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ABSTRACT

Wetland loss to agriculture in the Prairie Pothole Region of Canada has been widespread. Monitoring of wetlands restored via ditch plug to determine wildlife response has been minimal. In Camrose, Alberta (1999 and 2000) and Foam Lake, Saskatchewan (2000), I conducted surveys of restored and natural (reference) wetlands to assess wildlife use of restored wetlands. I compared bird assemblages in 97 restored and 85 natural wetlands using modified point counts. In 30 (15 restored) of these wetlands, I compared plant communities using quadrat-sampling techniques and amphibian abundance via trapping. Plant communities and amphibian abundance were similar in restored and natural wetlands in both provinces. In Alberta, bird assemblages were comparable in both wetland types. Although avian species richness was reduced in Saskatchewan restored wetlands, composition of wetland-dependent species was similar. Results indicate that restoration should continue to play a role in future wetland conservation strategies in Canada.

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TABLE OF CONTENTS

1. WETLAND LOSS AND RESTORATION IN THE PRAIRIE POTHOLE REGION

Wildlife use of wetlands 1
Wetland loss 3
Monitoring restored wetlands 5
Evaluating wetland restoration in Canada 7
Overview 9
Literature cited 10

2. A COMPARISON OF PLANT SPECIES RICHNESS AND COMPOSITION IN RESTORED AND NATURAL WETLANDS IN PRAIRIE CANADA

Introduction 13
Methods 16
    Study area 16
    Wetland selection 17
    Wetland morphometry 17
    Vegetation surveys 18
    Preliminary data analyses 20
    Data analyses 22
Results 24
    Wetland characteristics 24
    Species richness and diversity 25
    Cover and frequency by guild 25
    Alberta species composition 26
    Saskatchewan species composition 27
Discussion 27
Literature Cited 36

3. RECOVERY OF BIRD ASSEMBLAGES IN RESTORED WETLANDS IN THE PRAIRIE POTHOLE REGION IN ALBERTA, CANADA

Introduction 53
    Background 53
    Habitat characteristics 56
    Species richness and diversity 57
    Species composition 58
    Species-environment relationship 58
Methods 60
    Study area 60
    Wetland selection 60
    Habitat characteristics 61
    Bird surveys 63
Data Analyses 64
    Preliminary analyses 65
    Habitat characteristics 66
    Species richness and diversity 67

Species composition....................68
Species-environment relationship....................69
Results....................70
Habitat characteristics....................70
Species richness and diversity....................71
Species composition....................71
Species-environment relationship....................73
Discussion....................75
Summary....................84
Literature Cited....................84

4. RECOVERY OF BIRD ASSEMBLAGES IN RESTORED WETLANDS IN THE PRAIRIE POTHOLE REGION IN SASKATCHEWAN, CANADA

Introduction....................106
Methods....................109
Study area....................109
Wetland selection....................110
Habitat characteristics....................111
Bird surveys....................112
Data Analyses....................113
Habitat characteristics....................113
Species richness and diversity....................114
Species composition....................114
Species-environment relationship....................115
Results....................116
Habitat characteristics....................116
Species richness and diversity....................117
Species composition....................118
Species-environment relationship....................120
Discussion....................122
Literature Cited....................131

5. A COMPARISON OF AMPHIBIAN ASSEMBLAGES IN RESTORED AND NATURAL WETLANDS IN PRAIRIE CANADA

Introduction....................153
Methods....................158
Study area....................158
Wetland selection....................158
Surveys: trap methodology....................159
Surveys: observational records....................160
Habitat characteristics....................161
Data Analyses....................163
Restored versus natural wetlands....................164
Habitat relationships....................165
Results....................166
Species composition and trapping results....................166

Restored versus natural wetlands........168
Wood frog-habitat relationships........169
Discussion........170
Literature Cited........179

6. Summary and Management Recommendations........198
Literature Cited........202

Appendix 1........205
Appendix 2........206
Appendix 3........210
Appendix 4........214
Appendix 5........215
Appendix 6........216
Appendix 7........217
Appendix 8........218
Appendix 9........219
Appendix 10........220

List of Tables

Table 2.1: Wetland characteristics and community metrics for 9 restored and 9 natural wetlands near Camrose, Alberta and 6 restored and 6 natural wetlands near Foam Lake, Saskatchewan. 41

Table 2.2: Cover and frequency for common plant taxa observed in 9 restored and 9 natural wetlands in the Prairie Parkland of Alberta. 42

Table 2.3: Cover and frequency for common plant taxa observed in 6 restored and 6 natural wetlands in the northern Prairie Parkland of Saskatchewan. 43

Table 2.4: A comparison of the mean percent cover and percent frequency for each guild between 9 restored and 9 natural wetlands in Alberta, and 6 restored and 6 natural wetlands in Saskatchewan. 44

Table 2.5: Results of correspondence analysis (CA) applied to 18 wetlands (9 restored) with 42 plant species (including open water) in Alberta. 45

Table 2.6: Results of correspondence analysis (CA) applied to 12 wetlands (6 restored) with 41 plant species (including open water) in Saskatchewan. 45

Table 2.7: A comparison of guild species richness in restored and natural wetlands in the PPR of Alberta and Saskatchewan with a published species estimates from Galatowitsch (1993). 46

Table 3.1: Local and landscape features of 56 restored and 46 natural wetlands near Camrose, Alberta sampled in May - June 1999, 2000. 91

Table 3.2: Results of PCA for 15 habitat characteristics in 102 wetlands (56 restored) in Alberta and correlations between the habitat characteristics and scores from the first 3 axes of the PCA. 92

Table 3.3: Avian species observed in restored (56) and natural (46) wetlands in the Prairie Parkland near Camrose, Alberta, Canada. 93

Table 3.4: Results of Correspondence Analysis (CA) and Pearson correlations (r) for 15 habitat characteristics with axes applied to 100 wetlands (55 restored) with 22 bird species in the PPR of Alberta. 95

Table 3.5: Results of Canonical Correspondence Analysis (CCA) for bird assemblages in 102 wetlands (56 restored) near Camrose, Alberta. 96

Table 4.1: Local and landscape features of 41 restored and 39 natural wetlands near Foam Lake, Saskatchewan in sampled in May - June 2000 135

Table 4.2: Results of PCA for 15 habitat characteristics in 80 wetlands (41 restored) in Saskatchewan and correlations between the habitat characteristics and scores from the first 3 axes of the PCA. 136

Table 4.3: Fifty-two avian species documented in restored (41) and natural (39) wetlands in the Prairie Parkland near Foam Lake, Saskatchewan, Canada. 137

Table 4.4: Results of Correspondence Analysis (CA) applied to 80 wetlands (41 restored) with 30 bird species in the PPR of Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. 139

Table 4.5: Results of Correspondence Analysis (CA) applied to 80 wetlands (41 restored) with 13 upland bird species in Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. 140

Table 4.6: Results of Correspondence Analysis (CA) applied to 75 wetlands (37 restored) with wetland-dependent bird species in Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. 141

Table 4.7: Results of Canonical Correspondence Analysis (CCA) for bird assemblages in 80 wetlands (41 restored) near Foam Lake, Saskatchewan, Canada. 142

Table 5.1: A summary of wood frog pitfall trap and minnow trap catch-per-unit-effort comparisons for habitat characteristics. 184

Table 5.2: The results of a comparison of amphibian catch-per-unit-effort (CPUE) in Alberta wetlands trapped in 1999 versus 2000, and the results of comparison of amphibian CPUE between wetlands sampled in Alberta versus Saskatchewan in 2000. 185

Table 5.3: Results from comparisons of catch-per-unit-effort (CPUE) for 3 species of amphibians between restored and natural wetlands in Alberta 1999 and 2000 and Saskatchewan 2000. 186

Table 5.4: Results for comparisons for snout-vent-length (SVL) between restored and natural wetlands for 3 species captured in wetlands in Alberta 1999 and 2000, and Saskatchewan 2000. 188

Table 6.1: Summary of major findings and recommendations 204

List of Figures

Figure 2.1: Location of intensively sampled restored and natural wetlands in the Aspen Parkland of Alberta and Saskatchewan. 47

Figure 2.2: Wetland schematic illustrating the reorganization of quadrat data. 48

Figure 2.3a: Correspondence Analysis (CA) ordination of 18 Alberta PPR wetlands (9 restored) based on 42 plant species (including open water). 49

Figure 2.3b: Correspondence Analysis (CA) ordination of plant assemblages (41 species and open water) in 18 Alberta PPR wetlands (9 restored). 50

Figure 2.4a: Correspondence Analysis (CA) of plant assemblages (40 species and open water) in 12 Saskatchewan PPR wetlands (6 restored). 51

Figure 2.4b: Correspondence Analysis (CA) ordination of 12 Saskatchewan PPR wetlands (6 restored) based on 40 species and open water. 52

Figure 3.1: Location of 56 restored and 46 natural wetlands surveyed in the Aspen Parkland Ecoregion of Alberta, Canada. 97

Figure 3.2: Area included in avian point counts 98

Figure 3.3: Association of 102 Alberta PPR wetlands based on PCA of 15 local and landscape habitat characteristics. 99

Figure 3.4: Correspondence Analysis (CA) ordination of 100 Alberta wetlands (55 restored). 100

Figure 3.5: The relationship between (log) wetland size (m^2) and (log) species richness in 102 (56 restored) wetlands near Camrose, Alberta. 101

Figure 3.6: The relationship between wetland depth and species richness in 102 (56 restored) wetlands near Camrose, Alberta. 102

Figure 3.7: Correspondence Analysis ordination on 100 (55 restored) wetlands based on bird species assemblages (22 species). 103

Figure 3.8: Canonical Correspondence Analysis (CCA) ordination triplot of 100 wetlands (55 restored) in the Aspen Parkland of Alberta based on 22 bird species using 4 habitat characteristics. 104

Figure 3.9: The percentage of explained variation in bird assemblage composition attributed to local and landscape habitat characteristics 105

Figure 4.1: Location of 41 restored and 39 natural wetlands surveyed in the Aspen Parkland Ecoregion of Saskatchewan, Canada. 143

Figure 4.2: Association of 80 Saskatchewan PPR wetlands (41 restored) based on Principal Components Analysis (PCA) of 15 local and landscape habitat characteristics. 144

Figure 4.3a: Correspondence Analysis (CA) ordination of bird assemblages from 80 Saskatchewan wetlands (41 restored). 145

Figure 4.3b: Correspondence Analysis (CA) ordination of 80 Saskatchewan wetlands (41 restored) based on the presence or absence of 30 bird species. 146

Figure 4.4a: Correspondence Analysis (CA) ordination of 13 upland bird assemblages from 80 Saskatchewan wetlands (41 restored). 147

Figure 4.4b: Correspondence Analysis (CA) ordination of 80 Saskatchewan wetlands (41 restored) based on the occurrence of 13 upland bird species. 148

Figure 4.5a: Correspondence Analysis (CA) ordination of 75 Saskatchewan wetlands (37 restored) based on the presence or absence of 17 wetland-dependent bird species. 149

Figure 4.5b: Correspondence Analysis (CA) ordination of wetland-dependent bird assemblages from 75 Saskatchewan wetlands (37 restored) 150

Figure 4.6: Canonical Correspondence Analysis (CCA) ordination triplot of 80 Saskatchewan wetlands (41 restored) in the Aspen Parkland of Saskatchewan based on 30 bird species and 4 habitat characteristics. 151

Figure 4.7: Venn diagram illustrating differences in species assemblages between Alberta and Saskatchewan 152

Figure 5.1: Diagram illustrating the amphibian trap methodology for Prairie Pothole wetlands in Alberta and Saskatchewan. 189

Figure 5.2: A comparison of catch per unit effort rates in 7 restored and 7 natural wetlands for 3 amphibian species captured in minnow and pitfall traps near Camrose, Alberta, Canada 1999. 190

Figure 5.3: A comparison of catch per unit effort rates in 5 restored and 5 natural wetlands for 3 amphibian species captured in minnow and pitfall traps near Camrose, Alberta, Canada 2000. 191

Figure 5.4a: A comparison of catch per unit effort rates in 6 restored and 6 natural wetlands for wood frogs captured in minnow and pitfall traps near Foam Lake, Saskatchewan, Canada 2000. 192

Figure 5.4b: A comparison of catch per unit effort rates in 6 restored and 6 natural wetlands for boreal chorus frogs and tiger salamanders captured in minnow and pitfall traps near Foam Lake, Saskatchewan, Canada 2000. 193

Figure 5.5: A comparison of boreal chorus and wood frog occurrence in 102 Alberta (56 restored) and 80 Saskatchewan (41 restored) prairie wetlands. 194

Figure 5.6: Box and whisker plot of wood frog pitfall and minnow trap captu[illegible] rate by significant habitat characteristic categories in Alberta in 1999. 195

Figure 5.7: Box and whisker plot of wood frog pitfall capture rate by significant habitat characteristic categories in Alberta in 2000. 196

Figure 5.8: Box and whisker plot of wood frog pitfall capture rate by significant habitat characteristic categories in Saskatchewan in 2000. 197

CHAPTER 1

WETLAND LOSS AND RESTORATION IN THE PRAIRIE POTHOLE REGION

Wildlife use of wetlands

The millions of small freshwater wetlands that cover the landscape in the Prairie Pothole Region (PPR) were formed by glacial activity more than 10,000 years ago (Galatowitsch and van der Valk 1994). The region stretches over 780,000 km^2 in 3 provinces and 4 states in Canada and the United States (Mitsch and Gosselink 2000). Pothole wetlands are dynamic systems subject to a fluctuating water regime caused by the variability of the prairie climate (Kantrud, Millar and van der Valk 1989) and this cycle affects plant composition and wildlife use of individual wetlands. The majority of North American waterfowl production occurs in the PPR (Kantrud, Krapu and Swanson 1989) and production increases to almost 80% during good water years (Batt et al. 1989). A variety of species, including waterfowl, use wetland complexes composed of small and large basins of varying depths and vegetative cover with surrounding perennial cover for upland-nesting species (Galatowitsch and van der Valk 1994).

In pothole wetlands the pattern of vegetation is concentric zones, characterized by different communities that reflect the moisture gradient (Stewart and Kantrud 1971). Wetlands are classified based on the presence of one or more zones with diagnostic vegetation that reflect the duration of inundation (Stewart and Kantrud 1971). The zones (wetland class) in increasing permanence are low prairie (ephemeral, class I), wet meadow (temporary, class II), shallow emergent marsh (seasonal, class III), deep emergent marsh (semi-permanent, class IV) and open water (permanent, class V).

As well as influencing changes in wetland permanence and plant species composition (Stewart and Kantrud 1971), increases in wetland depth (Weller 1999) and wetland size (Kantrud and Stewart 1984) can increase the diversity and availability of habitat for wetland birds. Patterns of habitat diversity within a wetland can be described along gradients that correspond with the aforementioned vegetation zones. These patterns are reflected in the groups of birds that use these areas (Weller and Fredrickson 1974) and the probability of occurrence of individual species can be related to the percent of a basin covered by various zones (Fairbairn and Dinsmore 2001).

Diversity of avian nesting sites increases vertically beginning with floating nests used by, for example, black tern (*Childonias niger*), to nests at water level built into the emergent vegetation (e.g. rails, *Rallus* spp.), to nests built above water in sedges (e.g. wrens, *Cistothorus* spp.) and finally to nests built into the canopy of robust vegetation, such as *Typha*, spp. (e.g. yellow-headed blackbird, *Xanthocephalus xanthocephalus*). The nest site diversity also changes horizontally with increasing wetland depth from terrestrial (e.g. savannah sparrow, *Passerculus sandwichensis*, nesting in grasses; bufflehead, *Bucephala albeola*, in tree holes) to over-water nests (e.g. ruddy duck, *Oxyura jamaicensis*, in robust emergents) or open-water nests (e.g. grebes, Podicipedidae, on submergent vegetation).

The heterogeneity of pothole wetlands also includes varying degrees of vegetative cover. Cover includes emergent vegetation within a basin, the surrounding upland vegetation, complex convoluted shorelines, as well as the availability of open water for diving birds. Birds require cover for nesting, molting, resting, feeding and avoidance of predators and competitors (Murkin and Caldwell 2000, Weller 1999). Use of a particular wetland by birds may be associated more with the structure and cover pattern of vegetation than the actual plant species assemblage (Weller 1999, VanRees-Siewert and Dinsmore 1996).

Although PPR wetlands are often associated with diverse bird communities, they are intimately linked to the life cycles of a variety of wildlife species (Batt et al. 1989) and their importance to amphibians often goes unrecognized. Amphibians depend on a mosaic of wetland and terrestrial habitats through the course of the year for reproduction, foraging and hibernation (Semlitsch 2002, Reaser 2000). The duration of inundation of prairie wetlands has consequences for amphibian habitat selection. Hydroperiod must be sufficient for larval development and metamorphoses, but more permanent wetlands can have a more diverse predator community (fishes, diving beetles, or dragonfly larvae; Skelly 1997). The proportion of vegetation in a basin can be important for oviposition (Preston 1982), refuge, and for foraging or calling sites (Semlitsch 2002, Galatowitsch and van der Valk 1994). Amphibians disperse relatively short distances over land and the density of wetlands can affect the persistence of populations (Semlitsch 2002).

Wetland loss

Many wetlands have been drained, filled, burned or cultivated and these losses continue at an alarming rate. European colonization of the PPR over the last 150 years has resulted in large-scale changes to the wetland and grassland landscape through ever-increasing agriculture, urbanization, and industrialization (Gray et al.1999). A substantial proportion of wetland drainage has been for agricultural benefit. Wetland losses are estimated at 40% throughout the PPR (Canada/United States Steering Committee 1986 IN Turner et al. 1987) and as high as 70% near urban centers (Anonymous 1986), with more than 90% of the remaining wetlands negatively affected by agricultural expansion and urbanization (Neraasen and Nelson 1999). Loss of nesting cover, wetland drainage, and the degradation of migration and wintering habitat has resulted in long-term declines in duck populations (NAWMP 1986) and a disproportionate number of wetland-dependent species on endangered species lists (Gibbs 2000).

Declines in waterfowl populations prompted the governments of Mexico, United States and Canada to create the North American Waterfowl Management Plan (NAWMP) to coordinate efforts to improve habitat for waterfowl and other species (NAWMP 1986). NAWMP members recognized the value of wetland ecosystems as centers of biodiversity and they have made wetland habitat an important component of conservation and management goals to increase current waterfowl populations.

The majority of pothole wetlands have been drained using surface ditches and therefore, have the potential for restoration (Galatowitsch and van der Valk 1994). Here, I define restoration as the return of a wetland from a disturbed or drained condition to its pre-existing hydrological state, not specifically including the recovery of wetland function (Mitsch and Gosselink 2000, Gray et al. 1999). Restoration can be accomplished by breaking tile drains, plugging drainage ditches with earth, building dykes and constructing water control structures to halt drainage (Galatowitsch and van der Valk 1994). Past research has revealed that the return of water to a basin results in the recovery of some plant communities from remnant soil seed banks (e.g. emergent plants, *Typha* spp., van der Valk et al. 1992) and via seed dispersal (Galatowitsch and van der Valk 1994). The return of appropriate plant communities in restored wetlands is critical, because poor revegetation in restored wetlands will have negative consequences for the re-establishment of wildlife and biodiversity (Galatowitsch and van der Valk 1994).

Monitoring restored wetlands

Overall, monitoring wildlife use of restored wetlands following re-flooding has been minimal and there is a paucity of research assessing the adequacy of restored wetlands as wildlife habitat. Although there is some controversy regarding the possibility of truly successful restoration (Mitsch and Wilson 1996, Malakoff 1998, Ehrenfeld 2000), an evaluation of current restoration efforts is critical to the design and implementation of future conservation efforts. Monitoring restored wetlands provides information for improved management of these habitats and will increase the success of programs to mitigate wetland losses.

(Re)creation of wildlife habitat is often the goal of wetland restoration, and many managers and biologists agree that re-vegetation and wildlife use are indicators of a functional wetland (Gray et al. 1999). Although any re-flooded area could arguably provide more habitat for wetland-dependent wildlife than the alternative of having no wetland at all, the definitive test of a restored wetland's success may be its similarity to natural (undrained) wetlands in the surrounding area.

To date, all research regarding the re-establishment of plant communities and wildlife in restored wetlands has been conducted in the United States. LaGrange and Dinsmore (1989), Sewell and Higgins (1991) and Hemesath and Dinsmore (1993) documented the recovery of diverse plant communities, but each of these studies lacked a direct comparison to natural wetlands remaining in the area. Comparative studies (Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996a, 1996b) reported that plants of wet meadow and low prairie guilds were absent or reduced in restored wetlands. Only the most recent study of natural and restored wetlands has documented comparable habitat and cover types in both wetland types (Ratti et al. 2001).

The majority of investigations on restored wetlands have focused on avian use of the newly-flooded basins. LaGrange and Dinsmore (1989), Sewell and Higgins (1991), Hemesath and Dinsmore (1993) and VanRees-Siewert and Dinsmore (1993) found varying species richness with changes in wetland size and age among restored wetlands, but found no difference in species richness in comparison to literature values for natural wetlands. When restored wetlands were directly compared to natural wetlands, bird species richness was lower in restored wetlands (Delphey and Dinsmore 1993), paralleling a decreased variety of plant and invertebrate assemblages (LaGrange and Dinsmore 1989, Galatowitsch and van der Valk 1996a, 1996b). Again, findings by Ratti et al. (2001) did not concur. They found that restored wetlands supported similar numbers or more species as compared to natural wetlands.

Amphibians, in general, are poorly understood in the PPR, and their documentation in restored wetlands has primarily been anecdotal. Sewell and Higgins (1991) reported tiger salamanders (*Ambystoma tigrinim*) captured in restored wetlands (1-6 years post-restoration) while surveying fishes and invertebrates in Minnesota and North Dakota. Galatowitsch and van der Valk (1994) and Lannoo et al. (1994) reported rapid recolonization of restored wetlands by salamanders and Northern leopard frogs (*Rana pipiens*) in Iowa.

Evaluating wetland restoration in Canada

As principal delivery organization for NAWMP in Canada, Ducks Unlimited Canada (DUC) has been responsible for wetland restoration in the PPR of Canada . Throughout the PPR in Alberta, Saskatchewan and Manitoba, DUC has restored more than 900 wetlands and re-flooded almost 2000 ha between 1989 and 1997.

The present study addresses the need for information regarding wildlife use of restored wetlands and serves to assess the success of restoration in Prairie Canada by documenting bird and amphibian use and characterizing habitat features, including plant communities, on natural and restored wetlands. The use of a comparative design provides a common gauge and consistent means by which an evaluation of restoration efforts can be assessed (Mitsch and Wilson 1996, Delphey and Dinsmore 1993, Ratti et al. 2001). In coordination with DUC, areas were identified in the PPR where the company's restoration activity was highest. Two areas were chosen and surveys were conducted in 1999 and 2000 on 182 wetlands (Figure 2.1); 102 wetlands (56 restored) within 100 km of Camrose, Alberta, and 80 wetlands (41 restored) within 150 km of Foam Lake, Saskatchewan. Both areas are within the Aspen Parkland Ecoregion, an ecotone between the true prairies of the south and the boreal forest to the north located in the northern one-third of the PPR (Environment Canada 1996). This provided the opportunity to compare the success of restoration in 2 areas with similar habitat, but separated by >800 km and embedded in landscapes with different land use practices. The Alberta agricultural economy is dominated by the cattle industry, whereas Saskatchewan has historically been a grain-producing region (Statistics Canada 2001).

Restored wetlands were selected to represent the majority of DUC restoration efforts: small (<2 ha), Class III or IV (Stewart and Kantrud 1971), and restored between 1992 and 1997 with the construction of a ditch plug. Seasonal wetlands are characterized by an inner ring of shallow marsh vegetation (e.g. awned sedge, *Carex atherodes*), whereas semi-permanent wetlands have an additional zone of deep emergent marsh plants (e.g. *Typha* spp.) in the central zone of the basin. All wetlands were located on property managed by DUC with uplands of planted cover and comparable management histories. I have little information on previous land use on these properties or the duration of drainage for specific wetlands, and therefore could not incorporate these variables into the selection process. Natural or reference wetlands were relatively unaltered wetlands in the same area, located on DUC property and of similar size and permanence as restored wetlands. Surveyed wetlands (on the same property) were at least 100 m apart. Natural and restored wetlands were selected in a gradient of treatments and wetland density to incorporate various degrees of restoration and/or isolation: 'isolated' restored wetland, restored wetlands surrounded by other restored wetlands, restored wetland surrounded primarily by natural wetlands, natural wetlands in matrix of other natural wetlands, and 'isolated' natural wetlands. This ensured comparable representation of a variety of landscape configurations. All selected wetlands retained water in the spring, were located on uplands with surrounding uplands on DUC properties greater than one quarter section (>64.8 ha) in size. Because of the interest in bird communities, wetlands with perimeters of willow (*Salix* spp.) or aspen (*Populus* spp.) were not selected to avoid a predominance of woodland bird species (e.g. black-capped chickadees, *Poecile atricapillus*) that were not dependent on wetland habitats.

Overview

This thesis is presented as a series of chapters, each comparing the similarity of different taxa in natural and restored wetlands. Each chapter can be read as an individual paper and contains all the information necessary to understand the research presented.

The recovery of healthy plant communities is critical to the establishment of wildlife assemblages and is perhaps the first step in restoration. Chapter 2 discusses the results of a survey of plant communities in a sub-sample of natural and restored wetlands in Alberta and Saskatchewan. None of the restored wetlands were actively re-seeded, and by comparing the vegetation of these wetlands to that of natural wetlands, I determined if re-flooding was sufficient to restore plant communities.

As the primary goal of NAWMP is to improve the quality and quantity of avian habitats (Gray et al. 1999), Chapter 3 and 4 provide details on the use of natural and restored wetlands by bird assemblages in Alberta and Saskatchewan. Galatowitsch et al. (1999) found that use by wetland-dependent birds was the best community metric for wetland recovery. I compared avian species richness, diversity and composition between natural and restored wetlands and used multivariate techniques to explore the relationship between habitat characteristics and bird assemblages on individual wetland sites. Chapter 4 also presents a comparison of avian assemblages in restored wetlands between Alberta and Saskatchewan.

In Chapter 5, I present results on amphibian occurrence and abundance based on observational records and trapping adults and larvae in natural and restored wetlands. Amphibians, by nature of their permeable skin, are highly susceptible to physical and chemical changes in their environment. Amphibians are less mobile than birds, use aquatic and terrestrial habitats differently and we understand less of their ecology on the prairies. Amphibians, therefore, provide an alternate perspective on restored wetlands as functioning ecosystems.

Finally, Chapter 6 summarizes the conclusions from each of the preceding chapters and discusses their significance as it pertains to wetland restoration and management in Prairie Canada.

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CHAPTER 2

A COMPARISON OF PLANT SPECIES RICHNESS AND COMPOSITION IN NATURAL AND RESTORED WETLANDS IN PRAIRIE CANADA

INTRODUCTION

Historically, more than half the landscape in the Prairie Pothole Region (PPR) was comprised of millions of small (often <1 ha), shallow (<1 m) wetlands (Stewart and Kantrud 1971, Kantrud, Millar and van der Valk 1989) for which the region was named. These wetlands are productive ecosystems that provide critical wildlife habitat (Kantrud, Krapu and Swanson 1989). In some areas, settlement and agricultural expansion have resulted in the drainage or filling of more than 70% of these basins (Anonymous 1986), and have negatively impacted up to 90% of the remaining wetlands (Neraasen and Nelson 1999). Wetland loss in combination with the conversion of native uplands to crops has resulted in a severe loss of wildlife habitat. Restoring the hydrology and pre-drainage plant communities to drained basins is one means to mitigate loss.

Many small prairie wetlands have potential for restoration as they have only been superficially drained using surface ditches or tiles (Galatowitsch and van der Valk 1994). The typical method of restoration is to block the flow of water by placing an earth plug in the existing drainage ditch (Gray et al. 1999). Between 1989 and 1997, under the auspices of the North American Waterfowl Management Plan (NAWMP), Ducks Unlimited Canada (DUC) restored over 900 wetlands in Alberta, Saskatchewan and Manitoba, re-flooding almost 2000 ha of wetland habitat in the PPR (Gray et al. 1999). Past research has revealed that the return of water to a basin should result in the recovery of some plant communities from soil seed banks, such as emergent vegetation (e.g. *Typha* spp.), floating vegetation (e.g. *Lemna* spp.) and mudflat annuals (e.g. *Rumex* spp.; van der

Valk and Davis 1978, van der Valk et al. 1992). Submersed aquatic vegetation (e.g. *Potamogeton* spp.) will arrive at a newly flooded wetland via seed dispersal (Galatowitsch and van der Valk 1996a, 1996b). The return of healthy, comparable plant communities in restored wetlands is critical, because ultimately poor revegetation in restored wetlands has negative consequences for the re-establishment of wildlife and biodiversity (Galatowitsch and van der Valk 1994).

The distribution of plants in a prairie wetland is determined by water depth and duration of inundation (Kantrud, Millar and van der Valk 1989). The resulting pattern of vegetation is concentric zones, characterized by different communities that reflect the moisture gradient (Stewart and Kantrud 1971). In order of increasing flood duration, the five vegetation zones are: low/wet prairie, wet/sedge meadow, shallow emergent marsh, deep emergent marsh and permanent open water. The presence or absence of zones and their distribution within the wetland are used to designate 5 major classes of wetlands (Stewart and Kantrud 1971). This study focuses on wetlands of Class III and IV, seasonal and semi-permanent wetlands, respectively. Seasonal wetlands are dominated by an inner ring of shallow marsh vegetation, such as *Carex atherodes* (awned sedge), whereas semi-permanent wetlands have deep emergent marsh plants like *Typha* spp. (cattail) in the deepest part of the marsh and are typically inundated throughout the summer and frequently into the fall and winter (Stewart and Kantrud 1971).

Monitoring beyond the first year of flooding to determine wildlife response and the extent of habitat development in restored wetlands has been minimal. Early studies in the United States concluded that wetlands with plant and animal communities similar to natural wetlands can be adequately and easily restored by breaking tiles or plugging ditches without active re-vegetation (Madsen 1986, LaGrange and Dinsmore 1989, Sewell and Higgins 1991). Many habitat managers have worked under the assumption that revegetation of restored wetlands would occur naturally with the re-establishment of the hydrological regime (Gray et al. 1999, Galatowitsch and van der Valk 1994). However, revegetation patterns have proven to vary with the duration and effectiveness of drainage, past agricultural practices, and isolation from other wetland basins (Hemesath and Dinsmore 1993, Galatowitsch and van der Valk 1994, 1995). Plants characteristic of the wet meadow and low prairie zones are not abundant in most seed banks, and studies by Galatowitsch and van der Valk (1994, 1996b) and Delphey and Dinsmore (1993) found these species lacking in restored wetlands in northern Iowa. These two zones are usually efficiently drained (Galatowitsch and van der Valk 1996b) and the seeds of diagnostic plants are poorly represented in the seed bank due to brief viability (Wienhold and van der Valk 1989). Delphey and Dinsmore (1993) and Galatowitsch and van der Valk (1996b) advised active re-planting by managers to achieve successful restoration. All the aforementioned studies were conducted in the United States, and to my knowledge no similar research has been undertaken in the PPR of Canada. Also, many of the early studies assessing restored wetlands used published literature to designate expected plant communities rather than conducting surveys of natural wetlands to provide local references for comparison.

In the present study, I investigated the patterns of species richness and composition in restored and natural wetlands. I proposed that if the appropriate duration of inundation could be established for a given permanence class and a restored wetland had similar wetland quality and possessed a remnant seed bank; it would support a plant community that was similar to a natural or reference wetland. The study was conducted on 15 wetlands restored 3-7 years earlier by ditch plug, and 15 natural or reference wetlands of similar permanence in Alberta and Saskatchewan in the PPR of Canada. This effort was part of a larger investigation of use by birds (Chapter 3 and 4) and amphibians (Chapter 5) of 97 restored and 56 natural wetlands.

METHODS

Study Area

A total of 30 wetlands were intensively sampled within the Aspen Parkland Ecoregion of the PPR of Canada (Environment Canada 1996) in May through July of 1999 and 2000 (Figure 2.1). Eighteen wetlands were located within 50 km of Camrose, Alberta. Fourteen wetlands (7 restored) were surveyed in 1999 and 10 wetlands (5 restored) in 2000. Six wetlands (3 restored) were surveyed in both years of the study to assess annual variation. In 2000, an additional 12 wetlands were surveyed within 100 km of the town of Foam Lake, Saskatchewan. The Alberta and Saskatchewan study sites were approximately 800 km apart, and allow for the assessment of a habitat remediation technique in two key areas of DUC restoration activity in the PPR.

The Aspen Parkland has three main soil types; highly fertile black chernozemic soil, relatively less fertile grey luvisols and dark grey luvisols (Clayton et al. 1977). It has a harsh climate with a short growing seasons and low precipitation relative to other major agricultural areas of the world (Alberta mean annual precipitation=466 mm, Saskatchewan=347 mm; Total annual precipitation in Camrose, Alberta in 1999=454.4 mm, in 2000=388.9 mm and in Langenburg, Saskatchewan in 2000=414.0 mm; Environment Canada 1996). Mean summer temperatures are also similar with maximums of 22.5 and 25.4 °C and minimums of 9.4 and 11.7 °C in Alberta and Saskatchewan, respectively (Environment Canada 1996). Droughts are less frequent in this region than in the true Prairies to the south. Annual evaporation ranges from approximately 400 mm in Saskatchewan (Stoudt 1971) and 444 – 510 mm in Alberta (Smith 1971).

Wetland Selection

All selected wetlands were small (< 2 ha), seasonal (Class III) or semi-permanent (Class IV) wetlands (Stewart and Kantrud 1971) located on DUC purchased or leased property with surrounding uplands of planted cover or native parkland. All were freshwater (<40-500 μS/cm) to slightly brackish wetlands (500-2000 μS/cm)(Stewart and Kantrud 1971). Fifteen of the wetlands surveyed were natural or relatively unaltered wetlands that served as reference sites. Natural wetlands were randomly selected from approximately 125 wetlands of similar size and permanence located on DUC projects in Alberta and Saskatchewan. Restored wetlands (15) were randomly selected from a pool of more than 400 similarly sized restored wetlands in both provinces. Ditch plugs had been constructed by DUC engineering staff between 1989 and 1997 and were representative of the company's restoration efforts. For construction details see Gray et al. (1999). The majority (95%) of DUC's restoration activity was after 1992 (Gray et al. 1999) and this is reflected in the age of the wetlands surveyed (Appendix 1).

Wetland Morphometry

Maximum wetland depth (cm) was recorded weekly using graduated stakes placed in the deepest part of the wetland at the start of the field season. Conductivity (μS/cm) or specific conductance, was measured using a YSI model 33 S-C-T conductivity meter or a

Corning model TDS-60 portable conductivity meter. Conductivity was measured *in situ* prior to selection and twice in the lab during the field season in 1999, and weekly (*in situ*) in 2000. Conductivity is highly correlated with water salinity (Wetzel 1983) and served as an affordable proxy measurement thereof. Wetland area (m^2) was obtained by digitizing the post-restoration air photos (1:30 000) in Arcview 3.2 (ESRI 1992) and confirmed by visual estimates made twice during the field season. The extent of the basin was defined by the transition from low prairie vegetation to planted cover. Statistical comparison of wetland morphometry and conductivity between restored and natural wetlands was conducted using t-tests (Zar 1999).

Vegetation surveys

The species list was not intended to produce a complete list of species for each wetland; rather, the list provided a detailed subsample of species in each wetland to make valid comparisons of restored and natural wetlands. Some plants were identified only to genus and these belonged to genera with similar life history strategies (e.g. plants within the genus *Salix*). Such "genus only" taxa were treated by all analyses the same as true species, and will be referred to as 'species' hereafter.

In July of each study year, plant species composition in each wetland was documented using a non-overlapping system of quadrats similar to Delphey (1991). Along each of two, perpendicular transects (oriented north-south and east-west), 1-m^2 quadrats were sampled every 5 m. Transects began 10 m upland from the outer edge of the emergent vegetation and continued to the same point on the opposite side of the wetland. Water depth (cm) was recorded for each quadrat. Within each quadrat, approximate cover for each plant species was determined using the Daubenmire (1959) 6-

point cover-abundance scale; 1 = 0-5% (midpoint =2.5), 2 = 6-25% (15), 3 = 26-50% (32.5), 4 = 51-75% (62.5), 5 = 76-95% (85), 6 = 96-100% (97.5). Midpoints for each scale interval were used in calculations of cover and frequency. Canopy 'cover' for each species on a given wetland was the mean percent cover for all quadrats in which that plant was present, i.e. quadrats in which a species was not present were not included in calculations of mean cover. 'Frequency' of each taxon was the percentage of the total number of quadrats sampled on a wetland in which that species was observed. Together, cover and frequency provided a measure of the frequency of occurrence of a species and the mean ground cover that a species provided where found.

The number of quadrats sampled in each wetland varied according to wetland area. For analyses, to standardize the number of quadrats sampled at each wetland, species data was reorganized into 4 zones per wetland (Figure 2.2). For each basin, the first 2 and the last 2 quadrats of each transect were grouped into the 'upland' zone. The next 2 quadrats in each direction of each transect became the 'transition' zone. Following this pattern, the next 2 quadrats at each end of transects became 'wetland vegetation' and the remaining quadrats were part of the 'open water zone'. The open water of a permanent (Class V) wetland (Stewart and Kantrud 1971) differs from the open water areas in Class III or IV wetlands. The number of quadrats per zone (8) was reduced evenly for wetlands with less than 32 quadrats, and increased in the wetland vegetation and open water zone for those with greater than 32 quadrats. Alberta and Saskatchewan wetlands were surveyed using an average of 34 quadrats, with ranges of 16-59 and 25-49, respectively. Mean cover and frequency was determined for each of the 4 zones for each wetland. Mean cover/zone/wetland was used in all multivariate analyses.

Each plant species was classified into one of eight guilds based on life history strategy and flooding tolerance, following Galatowitsch and van der Valk (1994) and Stewart and Kantrud (1971). Deep emergent marsh (DEM) includes perennial plants that can withstand flooding and are often found at the edge of the open water in semi-permanent wetlands. Shallow emergent marsh (SEM) includes perennial plants that can withstand temporary flooding and are dominant in the shallow marsh zone of Class III and IV wetlands. Sedge meadow (SM) includes plants that endure flooding for only 1-2 months in the early spring and are found in the sedge meadow or wet prairie zones. Wet prairie (WP) includes grasses and forbs that cannot tolerate flooding for more than a few weeks. Upland (UPL) plants prefer well-drained soils and do not tolerate flooding. Woody plants (WO) plants include willows (*Salix* spp.) and poplars (*Populus* spp.). Mudflat annuals (MF) plants are common in unvegetated areas, such as the areas of drawdown in wetlands and include many agricultural weeds. Floating annuals (FA) includes annual plants such as duckweed (*Lemna minor*), and submersed aquatic vegetation (SA) includes annuals that grow within the water column (adapted from Galatowitsch and van der Valk 1994). Only DEM, SEM, SM, and WP plants were used in wetland classification. The proportion of open water (i.e. flooded and not vegetated) within each quadrat was also recorded and included in analysis.

Preliminary Data Analyses

As wetlands were sampled in 2 years, preliminary analyses were conducted to determine annual variation and explore combination of 2 years of data in further analyses.

Annual variation in species composition of Alberta wetlands was determined using both Mantel tests (PCOrd 4.0, McCune and Mefford 1999) and PROTEST analysis

(MSDOS program, Jackson 1995). Plant species composition, entered as mean percent cover, was compared between 1999 and 2000 for 6 wetlands (3 restored) surveyed in both years. Mantel tests were used to assess the correlation between the 2 matrices (Euclidean-distance matrices derived from original matrices), by using Monte Carlo randomization (9999 permutations) to test whether or not the observed correlation is different from random (Mantel 1967; McCune and Mefford 1999; Peres-Neto and Jackson 2001). PROTEST (Jackson and Harvey 1993) is a technique that uses randomization testing based on procrustean matrix rotation to assess concordance between matrices. This method aims to match the position of each wetland in one multivariate space [the first 3 correspondence analysis (CA, described below) axes of 6 wetlands surveyed in 1999] with the position of the same wetland in a second multivariate space (the first 3 CA axes of the same 6 wetlands surveyed in 2000; Paszkowski and Tonn 2000). This eliminates the variation associated with the selection of an appropriate distance measure (metric used to determine distance between objects in multivariate space, for example Euclidean distance used in above Mantel test) and overall has been shown to be more powerful than Mantel tests (Peres-Neto and Jackson 2001). There are many varieties of distance measures related to the domain of x and distance measure choice can have an effect on the outcome of analyses.

My results from these analyses indicated a strong similarity in the plant species composition between years in Alberta wetlands sampled in both 1999 and 2000 (PROTEST $r = 0.58$, $p<0.001$; Mantel $r = 0.47$, $p<0.001$). The Alberta data was therefore combined into a data set of the 10 wetlands surveyed in 2000 and the 8 wetlands surveyed only in 1999 (total = 18 wetlands, 9 restored). This composite data set will be used in all subsequent analyses and referred to as Alberta wetlands.

I compared plant species composition of wetlands between Alberta and Saskatchewan by conducting a Multi-Response Permutation Procedure (MRPP, Zimmerman et al. 1985), using Euclidean distance, on the sites scores for the first 3 axes from a CA. MRPP is non-parametric version of discriminate analysis and was used as a means of statistically comparing species composition between wetlands in Alberta and Saskatchewan. This analysis was performed on all natural wetlands, 9 in Alberta and 6 in Saskatchewan.

Plant species composition in natural wetlands was significantly different between Alberta and Saskatchewan (MRPP test statistic $T = -2.70$, $p = 0.03$). Due to the observed differences in reference wetlands, communities from Alberta and Saskatchewan were analyzed separately.

Data Analyses

Species richness (S) was defined as the total number of species, including rare species, observed in the quadrats sampled on a given wetland. Species diversity for each wetland was determined using Shannon's diversity index (H) and equitability measure (E_h), and was based on the proportion or frequency of each plant species identified in the quadrats. The diversity index takes into account the abundance and number of species present and equitability provides a measure of species' relative abundance or evenness of occurrence (Begon et al. 1990).

As previous studies in the southern PPR found expected vegetation zones and species absent, rare or reduced in restored wetlands, I compared the mean cover and frequency for each guild between wetland types (restored and natural) using a (non-parametric) Mann-Whitney U-test (Zar 1999).

Multivariate ordination techniques, Detrended Correspondence Analysis (DCA, Hill and Gauch 1980) and Correspondence Analysis (CA; PCOrd 4.0, McCune and Mefford 1997) were used to compare patterns in species composition of restored and natural wetlands and to visually assess community data. Mean percent cover for each species in each designated wetland zone (upland, transition, wetland vegetation and open water) was used in all community analyses. Thus, there were 4 records of species composition for each wetland. It should be noted that analyses were also conducted with presence or absence of species data, and similar results were achieved. Depth was the only explanatory variable that was collected at the quadrat level. Species observed in less than 2.5% of quadrats sampled (10.25 quadrats in Saskatchewan and 15.65 quadrats in Alberta) were considered rare and eliminated from analyses of species composition. Rare species can skew the data set because ordination techniques can perceive these rare species as outliers. Similarly, rare or uncommon species are often anomalies rather than an indication of ecological integrity (Gauch 1982).

Plant assemblages in Alberta and Saskatchewan were examined using CA after prior analyses (using DCA) indicated that the gradient length for the first axis was >2 standard deviation units suggesting a unimodal distribution of species. CA is an unconstrained unimodal ordination technique that simultaneously ordinates sites and species on complementary axes (Gauch 1982, McGarigal et al. 2000). An unconstrained ordination summarizes community data by reducing the number of dimensions in the data and producing a space in which similar species and sites are grouped (Gauch 1982) based on interrelationships within the data set irrespective of actual environmental variables (McGarigal et al. 2000). The CA site scores, weighted averages for the species scores for all species that occur on a wetland (Palmer 1993), were used in subsequent MRPP analysis to assess the plant species composition between restored and natural wetlands. The use of scores for MRPP analysis of biotic data reduces the bias in this analysis that may be produced by zeroes (species not present) in the original data matrix (W. Tonn, University of Alberta, pers. commun. 2001).

On CA ordinations, confidence ellipses were plotted using SYSTAT 9.0 (SPSS, Inc. 1998) to graphically highlight the position of mean restored and natural wetland points. The ellipses were centered on sample means for x and y and drawn using the unbiased sample deviations for x and y to determine the major axes and the sample covariance to determine orientation. The size of ellipses was based on a probability of 0.683 (SPSS, Inc. 1998).

RESULTS

Wetland Characteristics

All wetlands surveyed in Saskatchewan were classified as semi-permanent wetlands (Class IV, Stewart and Kantrud 1971). In Alberta, a total of 6 wetlands (3 restored) were classified as seasonal (Class III, Stewart and Kantrud 1971), with the remaining wetlands (12) classified as semi-permanent (Class IV). Restored and natural wetlands in both provinces were of comparable size and depth (Table 2.1). Conductivity was also not significantly different between wetland types in Alberta ($\bar{x}_{natural}$=866.5 µS/cm, $\bar{x}_{restored}$=545.5 µS/cm, p=0.13) but restored wetlands in Saskatchewan had lower conductivity ($\bar{x}_{natural}$=1021.7 µS/cm, $\bar{x}_{restored}$=537.5 µS/cm, p=0.03; Table 2.1).

Species richness and diversity

In Alberta, a total of 76 plant species were observed in natural wetlands, whereas 67 species were identified in restored wetlands (Table 2.2). In Saskatchewan, 63 plant species were recorded in natural wetlands and 61 species were observed in restored wetlands (Table 2.3). Twenty-eight taxa were observed in both provinces. Although there were a greater number of species observed in natural wetlands, species richness did not differ significantly with wetland type in either province. Both restored and natural Alberta wetlands had a mean of 32 plant species per wetland, with comparable ranges in each wetland type (Table 2.1). Likewise, in Saskatchewan, the mean number of species observed for each basin was 33 species for both wetland types with a similar range of species (Table 2.1).

At both study areas (Alberta and Saskatchewan), overall species lists for each wetland type were similar (Table 2.2 and 2.3). In almost all cases where a plant was observed in only one wetland type, that species was observed in only a few quadrats (<5) in a single wetland.

Mean species diversity for each wetland type, assessed using Shannon's diversity index (H), was not statistically different between wetland types in either province (Table 2.1). The corresponding equitability or evenness measure (E_h), was also comparable in both provinces (Table 2.1). However, there was greater variation in E_h for Saskatchewan restored, as compared to natural, wetlands and results of the t-test were significant ($t=2.183$, d.f.=10, $p=0.05$).

Cover and frequency by guild

In all wetlands, I observed representatives of each of the expected life history guilds for both wetland classes. For each guild, mean cover and frequency did not differ between restored and natural wetlands in either province based on Mann-Whitney U-tests (Table 2.4). Plant species in the DEM, MF, and WO guilds were not present in all wetlands. In Alberta, 4 wetlands (1 restored) lacked DEM vegetation, 5 wetlands (2 restored) had no MF vegetation and 6 wetlands (4 restored) had no WO vegetation. In Saskatchewan, 5 wetlands (1 restored) lack MF vegetation and 2 natural wetlands had no WO vegetation.

Alberta species composition

Forty-one species of plants and one open-water habitat category (=42) were included and rare species were downweighted in CA for Alberta wetlands (Table 2.5, Figure 2.3a). There was substantial overlap of restored and natural wetlands on the first and second axes, as illustrated by the confidences ellipses (Figure 2.3b). The first CA axis had an eigenvalue of 0.70 and accounted for 35% of the variation in the species data. Site scores on this axis were highly correlated with water depth measured in each quadrat ($r^2 = 0.68$). The designated zones also followed an expected pattern along the depth gradient of axis 1, with 'upland' vegetation at the left and 'open water' and 'wetland vegetation' to the right. This pattern was consistent for restored and natural wetlands. Comparison of the CA scores of restored and natural wetlands in Alberta using MRPP approached significance of $p \leq 0.05$ ($T = -1.69$, $p = 0.07$) highlighting minor differences related to wetland size and species composition between wetland types.

Saskatchewan species composition

Analysis of Saskatchewan species composition yielded similar results to those of Alberta. Forty species of plants and one open-water habitat category (=41) were included with rare species downweighted. Graphs of CA results and overlaying ellipses illustrated a great deal of overlap between restored and natural sites on the first and second axes (Table 2.6, Figure 2.4a and 2.4b). The eigenvalue for axis 1 was 0.62, explaining 41% of the variation in the plant species data. The first axis was highly correlated with wetland depth for each quadrat ($r^2 = -0.81$). As with the Alberta CA, designated zones followed the depth gradient along the first axis from shallow 'upland' vegetation to the deepest part of the wetland 'open water' zone. Both restored and natural wetlands followed this pattern. The interspersion of restored and natural wetland sites (Figure 2.4b) was supported by the results of MRPP on CA scores ($T = -0.19$, $p = 0.32$) indicating a similarity greater than expected by chance in the species composition for the two wetland types.

DISCUSSION

In the Prairie Parkland of Alberta and Saskatchewan, restored wetlands between 3 and 7 years of age possessed plant communities that were not significantly different than natural wetlands of similar size and permanence.

The natural and restored wetlands in my study were of similar size and depth. Conductivity in Alberta was also comparable between the wetland types, but conductivity in Saskatchewan restored wetlands was lower than that of the reference wetlands. Wetland selection was based primarily on size and depth, and specific conductance was measured to assure that wetlands were not overly saline, which would preclude the establishment of amphibians (Chapter 5). Salinity within a wetland is primarily a product of evaporation, and can be decreased by groundwater recharge (Murkin et al. 2000). Cultivation and siltation, which drained wetlands frequently experience, negatively affect porosity of wetland basins, and ultimately affect the flow of groundwater out of wetlands (Kantrud, Millar and van der Valk 1989, Kantrud and Newton 1996). Research suggests that most restored wetlands will be groundwater recharge sites with lower conductivity (Knutsen and Euliss 2001). Galatowitsch and van der Valk (1996c) also observed lower conductivity in restored wetlands within the range of salinity tolerance for most aquatic hydrophytes, and attributed the differences to processes related to vegetation development.

Lower conductivity of restored wetlands in Saskatchewan likely reflects differences in groundwater contributions caused by past disturbance in the landscape. The distribution and abundance of aquatic plants reflects the salinity of the wetland (Kantrud, Millar and van der Valk 1989) and salinity will affect the establishment and distribution of emergents and annuals (Murkin et al. 2001). Therefore, although I observed differences in conductivity between restored and natural wetlands similar to Galatowitsch and van der Valk (1996c), plant communities in Saskatchewan did not indicate this difference was biologically significant.

Species richness, diversity and species equitability were similar (Table 2.1) in restored and natural wetlands in both provinces. Slight differences in how evenly species were distributed within communities, E_h (Begon et al. 1990), in Saskatchewan wetlands was driven primarily by greater variability among restored wetlands perhaps reflecting minor differences in restored wetland age or more dynamic vegetation patterns in restored wetlands as basin conditions equilibrate.

All of the designated species guilds (Galatowitsch and van der Valk 1994, Stewart and Kantrud 1971) were observed in restored wetlands, and no anticipated guilds were observed to be completely lacking. The absence of the DEM plant guild in 4 of 18 wetlands is expected as I surveyed both seasonal and semi-permanent wetlands. Class III (seasonal) wetlands do not have DEM vegetation as they do not usually retain water through the annual cycle that is required to support these plant species (Stewart and Kantrud 1971). Similarly, not all wetlands possessed MF and WO plant species, but these are not guilds that are used in classification and therefore are not expected in all wetlands. The frequency of occurrence and amount of cover provided by each plant guild were similar in restored and natural wetlands. Whereas, previous studies in the southern PPR failed to observe WP and SM species in restored wetlands (Galatowitsch and van der Valk 1994, 1996a, Delphey and Dinsmore 1993), my results found these species to occur with similar frequency and ground cover as natural wetlands in my northern PPR sites.

In Alberta, the similarity in plant species composition in restored and natural wetlands was supported by CA and MRPP analyses. Minor differences in species composition between wetland types in Alberta (e.g. MRPP results) may have been driven by the presence of several zones from a smaller restored wetland (0.04 ha) that lay outside the 68.3% confidence ellipse or by the presence of species such as *Hordeum jubatum* (foxtail barley) in many restored wetlands. Foxtail barley, found only on restored wetlands (6 of 9), is a native plant that is a prolific seed producer that can easily become established in newly seeded pasture (Stearman 1983). Its habitat includes disturbed ground and moist depressions. It is probable that initial construction of the ditch plug provided ideal conditions for the invasion of this perennial in restored wetlands.

As was true for Alberta wetlands, CA indicated that plant species composition was extremely similar between restored and natural wetlands in Saskatchewan. There was substantial overlap of restored and natural wetlands, and this pattern was strongly supported by MRPP analysis. Not unexpectedly, given the organization of plant species data, the wetland sites on the ordinations followed a depth gradient along the first axis from upland to open water zones. Both provinces displayed this pattern.

Many of the species that were found in only one of the wetland types were found in very low frequency and were uncommon in the area, such as marsh skullcap (*Scutellaria galericulata*) and giant bur-reed (*Sparangium eurycarpium*; Johnson et al. 1995). Other species found in one wetland type (here, restored) were weeds, such as *Tanacetum vulgare* (tansy) and *Cerastium nutans* (prairie chickweed) that commonly invade disturbed lands. *Dactylis glomerata* (orchard grass) was seeded into the uplands near the two natural wetlands where it was found (Todd Holmquist, DUC habitat specialist, pers. commun. 2001) and is a weedy species often dispersed by birds (Stearman 1983, D. Henderson, University of Alberta, pers.commun. 2001).

Galatowitsch and van der Valk (1994) stated that the definitive benchmark of success for restoration is the restored wetland's similarity to natural wetlands in the surrounding area. Although I observed some minor differences in vegetation, restored wetlands in Alberta and Saskatchewan resembled local natural wetlands and appeared to successfully counteract wetland loss. Does this mean that these restored wetlands are 'healthy' (i.e. of adequate environmental quality or a biologically viable and sustainable wetland ecosystem)? To answer this question, I must first examine the health of natural wetlands that serve as references. Contemporary wetlands are subject to a variety of direct and indirect agricultural disturbance besides drainage. Historically, prairie wetlands were disturbed by fire, drought, and grazing by native ungulates. Since European settlement, disturbances include cultivation, domestic grazing, mowing, road construction, siltation and pesticide or fertilizer input (Kantrud, Millar and van der Valk 1989, Walker and Coupland 1970). There have been few efforts to assess wetland quality or health. Kantrud and Newton (1996) attempted to isolate disturbance effects on the health of prairie pothole wetlands but found their inherent instability made environmental quality difficult to quantify. Galatowitsch (1993) estimated the number of plant species that a depauperate, typical, or exceptional quality wetland (0.4-8 ha) in the southern PPR would possess in each of the life history guilds (Table 2.7). Although the numbers of species I observed in each guild would categorize my study wetlands as depauperate by Galatowitsch and van der Valk's (1994) benchmark, the wetlands of this study were small (<1 ha) and species lists were based on sub-sampling techniques in which all plants were not identified to the species level. I observed several species in each of the life history guilds in wetlands <0.2 ha in size, suggesting species richness in my reference wetlands can be considered 'typical'. Additionally, truly poor quality wetlands show little use by aquatic birds (Kantrud and Newton 1996) and this is not the case in the restored wetlands of this study (Chapter 3 and 4). I therefore concluded that the natural wetlands used in this study display vegetation patterns consistent with the classification system of Stewart and Kantrud (1971) and provide adequate reference sites to assess plant assemblages in restored wetlands.

Why is the outcome of re-vegetation in restored wetlands in Canada different from those in the southern PPR? The apparent increased success in the northern PPR may be related to the efficiency of drainage. The majority of the restored wetlands monitored in Iowa, Minnesota, North and South Dakota were previously tile-drained (LaGrange and Dinsmore 1989, Sewell and Higgins 1989, Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996a, 1996b, and VanRees-Siewert and Dinsmore1996). Wetlands drained by tile have been found to be slow to revegetate, have depauperate seed banks, and rarely recover wet prairie and sedge meadow plant species (Galatowitsch and van der Valk 1994). Almost all of the wetlands restored by DUC between 1989 and 1997 had been drained by surface ditches (Gray et al. 1999). Wetlands drained by this method have a higher revegetation potential (Galatowitsch and van der Valk 1994) due to sporadic inundation and retention of some emergent species within the ditch itself.

It is important to note that the wetlands in this study were restored in the original basin. My results do not project the revegetation potential for mitigation projects involving wetland creation, specifically, the conversion of uplands to vegetated wetlands (Mitsch and Gosselink 2000). No long term studies have shown that a created wetland can replace the function lost by wetland destruction or that a created wetland can provide in-kind compensation for wetland loss (Hunt 1996).

Although specific pre-drainage history for my study sites is unknown, it is believed that these wetlands were drained for 10 years on average (Gray et al. 1999). Many of wetlands studied in Iowa, Minnesota and South Dakota had been farmed for more than 50 years (Galatowitsch and van der Valk 1996a). Drainage in Iowa began in 1900 when wetlands comprised more than 70% of the landscape. By 1925, less than 1% of the area was covered by wetlands (Galatowitsch and van der Valk 1994). In Canada, between 30% and 60% of the original wetlands remain, and drainage only became commonplace in the 1970's (Gray et al. 1999; Canada/United States Steering Committee 1986 IN Turner et al. 1987). Later development of intensive agricultural activities in Canada corresponds with a shorter average length of drainage. This can be advantageous for restoration because relict wetland seed banks survive up to 20 years and can be further replenished during wet periods (van der Valk and Davis 1978, Erlandson 1987). Wetlands restored in Canada may have possessed many species still viable in seed banks, increasing the likelihood of restoring a plant community similar to surrounding natural wetlands.

Another potential explanation for the difference in restoration success is the extent of drainage at a larger landscape scale. Drainage has been more extensive in the southeastern parts of the PPR (Kantrud, Millar and van der Valk 1989). A larger population of original, undrained wetlands will provide a source pool of seeds and propagules that can aid in the revegetation of restored wetlands. In the United States, it has been proposed that the number of natural wetlands in some landscapes is insufficient to supply propagules to re-flooded basins (Galatowitsch and van der Valk 1994). Within the PPR, the number of wetlands increases northward and the greatest number of wetlands is found in the aspen parkland and northern grasslands of Canada (Environment Canada 1996). Very few of the wetlands surveyed in my study area were found within parcels of land (65 ha) where all basins had been completely drained and none were >500 m from another flooded basin. In comparison, with fewer historical wetland basins per ha and a greater extent of drainage, the southern PPR has undoubtedly been left with few natural basins to act as source populations. Dispersal of seeds and propagules between restored and natural wetlands in Canada may be more reliable and therefore result in more complete plant communities (including WP and SM species) on restored wetlands.

It should also be noted that the variability of the prairie climate is an important factor in the hydrology of prairie wetlands, and that there are differences in the climate of the Aspen Parkland and southern Prairie Pothole Region. Melting snow and summer precipitation are the main sources of water in the wetlands, and water can be lost to evaporation and transpiration from the open water zone and evapotranspiration from surrounding vegetation (van der Kamp et al. 1999). Therefore, differences in precipitation or evaporation in the prairies of the United States may affect the probability of successful wetland restoration.

Is there room for further management in the northern PPR? Galatowitsch and van der Valk (1994) outline 4 circumstances under which active management of restored wetlands may be advisable based on case studies in the United States. Management is recommended for a restored wetland that possesses sparse or no vegetation after 3 or more years. My results indicate that wetlands restored 3 to 7 years prior to study, supported vegetation similar to that of surrounding natural wetlands, and all expected guilds were represented. The second recommendation was that a wetland that lacks one or more vegetative guilds requires active planting of species such as members of wet prairie and sedge meadow guilds. I have shown that restored wetlands in the parkland of Alberta and Saskatchewan supported expected wetland plants from all guilds and planting appears unnecessary. The third recommendation was that a wetland with aggressive weeds such as *Cirsium arvense* (Canada thistle) and *Phalaris arundincaea* (canary reed grass) should be managed immediately and intensively. These species were present in both wetland types in this study. *C. arvense* was more common than *P. arundincaea*, but both weed species were found in similar frequency in restored and natural wetlands. Therefore, I would advise active management of weed species in both wetland types, when necessary.

Finally, Galatowitsch and van der Valk (1994) recommend management to prevent the establishment of woody species (*Salix* spp. and *Populus* spp.) within wetlands. The amount of cover provided by willow and aspen in both restored and natural wetland my study was relatively small (less than 10% of the surrounding 78 ha and mean distance to woodland was 100m). During wetland selection, because of interest in bird communities, care was taken to avoid wetlands within thick aspen or willow in order to avoid counting/surveying woodland bird species such as flycatchers (*Empidonax* spp.) and black-capped chickadees (*Poecile atricapillus*) that were not necessarily utilizing wetland habitat. Over time, woody vegetation may develop in restored wetlands. The study was located on the northern border of the PPR within the Aspen Parkland Wetland district where wetlands are distinguished from the southern parts of the region by the frequent occurrence of a woody border around wetlands (Kantrud, Millar and van der Valk 1989). Higher precipitation and reduced fire frequency further north produces differences between aspen parkland and grassland ecosystems. There is evidence that aspen (*Populus tremuloides*) is expanding on the southern border of the aspen parkland and encroaching on adjacent grassland (Archibold and Wilson 1980) due to the suppression of fires (Anderson and Bailey 1980, Buell and Buell 1959) and wild ungulate grazing (Rowe 1987). Managers must decide if woody vegetation around wetlands is beneficial to native species such as the common goldeneye (*Bucephela clangula*) or bufflehead (*Bucephela albeola*) which nest in trees or is detrimental to other species by providing perches for predators such as corvids (*Corvus* spp.) or hawks (*Buteo* or *Accipiter* spp.).

Restoration of drained prairie pothole wetlands in the northern PPR of Alberta and Saskatchewan has resulted in newly flooded Class III and IV wetlands with plant communities that resemble those of natural (relatively unaltered) wetlands in the surrounding area under DUC management. Active replanting is not necessary, but some management of weedy species or woody vegetation in restored and natural wetlands may be required. In comparison to some restoration failures in the southern PPR, the shorter duration of drainage, less efficient ditching methods and higher density of remaining natural wetlands have resulted in relatively rapid revegetation of restored wetlands and these sites are not distinguishable from their less disturbed counterparts.

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Table 2.1: Wetland characteristics and community metrics for 9 restored and 9 natural wetlands near Camrose, Alberta and 6 restored and 6 natural wetlands near Foam Lake, Saskatchewan. In Alberta, none of the wetland characteristics or community metrics differed significantly ($p<0.05$) between wetland types. Conductivity is significantly higher in natural wetlands in Saskatchewan ($p<0.05$). The range (minimum to maximum) in the measure of species eveness (Eh) is greater in restored wetlands than in natural ($p<0.05$).

		ALBERTA					SASKATCHEWAN				
		Natural	Restored	t	df	p	Natural	Restored	t	df	p
Class*	III	3	3				0	0			
	IV	6	6				6	6			
Wetland characteristics											
Size (m^2)	Mean	1979.3	2474.1	-0.56	16	0.59	2287.5	2861	-0.58	10	0.57
	Range	405 - 4049	405 - 7692				810 - 4049	1215 - 6073			
Maximum depth (cm)	Mean	41.8	31.6	1.02	16	0.33	41.8	36.8	1.35	10	0.21
	Range	8 - 86.5	1 - 50				26 - 58	20 - 67			
Conductivity (µS/cm)	Mean	866.5	545.5	1.58	16	0.13	1021.7	537.5	2.61	10	0.03
	Range	298 - 1635	205 - 1321				470 - 1400	290 - 875			
Community metrics											
Species Richness (S)	Mean	32	32.33	-0.10	16	0.92	33.17	32.67	0.11	10	0.91
	Range	19 - 44	28 - 40				21 - 42	27 - 45			
Species Diversity (H)	Mean	3.06	3.09	-0.39	16	0.70	3.19	3.07	0.906	10	0.39
	Range	2.68 - 3.36	2.91 - 3.26				2.85 - 3.45	2.78 - 3.35			
Equitability (Eh)	Mean	0.89	0.89	0.14	16	0.89	0.92	0.88	2.183	10	0.05
	Range	0.88 - 0.91	0.84 - 0.92				0.88 - 0.94	0.83 - 0.93			

* as per Stewart and Kantrud (1971)

Table 2.2: Cover and frequency for common plant taxa observed in 9 restored and 9 natural wetlands in the Prairie Parkland of Alberta. Common species were included in multivariate analysis and are defined as species that were observed in more than 2.5% of the quadrats sampled in each province. Canopy cover for each taxon was determined using the mean percent cover for all quadrats in which that plant was present on a given wetland. Frequency is defined as the number of observations of a plant species or genera as a percentage of the total number of quadrats sampled per wetland. Guild abbreviations are discussed within the text of the methods.

				NATURAL WETLAND			**RESTORED WETLAND**		
					77 species			**68 species**	
Code	**Guild**	**Scientific Name**	**Common Name**	**% COVER**	**% FREQ**	**# PONDS**	**% COVER**	**% FREQ**	**# PONDS**
AGSP	WP	*Agropyron* species	wheatgrass	42.8	18.3	8	44.8	24.2	9
ALAE	SEM	*Alopecuris aequalis*	short-awned foxtail	17.9	2.1	2	33.0	12.4	7
BESY	SEM	*Beckmannia syzigachne*	slough grass	26.4	4.9	4	21.9	19.5	9
BRSP	SM	*Bromus* species	brome species	61.2	12.5	6	60.7	7.7	6
CAAT	SEM	*Carex atherodes*	slough sedge	60.3	32.0	9	51.9	30.2	7
CASP	SM	*Carex* species	sedge species	44.3	21.0	9	44.6	27.9	9
CIAR	SM	*Cirsium arvense*	Canada thistle	19.3	27.7	9	15.5	24.5	9
ELPA	SEM	*Eleocharis palustris*	creeping spikerush	26.3	0.6	1	18.7	5.7	4
ELSP	SEM	*Eleocharis* species	spikerush species	34.2	1.8	4	39.7	15.1	4
EQPR	SM	*Equisetum pratense*	meadow horsetail	5.6	2.4	2	34.2	2.0	2
FESP	UPL	*Festuca* species	fescue species	16.7	1.8	2	25.0	4.7	4
GASP	WP	*Galium* species	bedstraw species	9.4	2.7	3	10.8	3.0	2
GATE	UPL	*Galeopsis tetrahit*	hemp-nettle	10.0	3.0	5	7.2	2.7	5
GATR	SM	*Galium trifidum*	small bedstraw	15.0	0.3	1	13.4	3.7	2
GEAL	WP	*Geum aleppicum*	yellow avens	11.9	2.7	5	11.9	4.0	5
GLGR	SEM	*Glyceria grandis*	tall mannagrass	22.3	3.4	3	22.0	16.1	3
GLPU	SM	*Glyceria pulchella*	graceful mannagrass	24.8	9.8	9	30.6	19.8	8
HOJU	WP	*Hordeum jubatum*	foxtail barley	0.0	0.0	0	9.2	5.0	6
JUBA	SM	*Juncus balticus*	wire rush	48.8	12.2	7	19.8	4.0	6
KOCR	UPL	*Koeleria cristata*	june grass	23.4	7.3	7	8.8	0.7	1
MEAR	SM	*Mentha arvense*	wild mint	18.3	11.3	7	9.4	5.4	4
MESA	UPL	*Medicago satium*	alfalfa	19.5	10.7	8	24.0	8.4	8
OPWA	OPWA	---	open water	59.1	49.7	9	50.5	49.0	9
PHPR	UPL	*Phleum pratense*	timothy	8.8	1.8	3	13.8	4.4	6
POAM	SEM	*Polygonum amphibian*	smartweed	16.4	2.1	2	5.0	3.4	4
POAN	WP	*Potentilla anserina*	silverweed	16.4	13.1	7	11.9	1.3	2
POPA	SM	*Poa palustris*	fowl bluegrass	35.3	8.5	9	31.6	15.1	8
POPR	WP	*Poa pratense*	kentucky bluegrass	42.5	17.4	8	38.8	6.7	4
POSP	WO	*Populus* species	poplar	38.3	1.8	2	42.3	3.7	4
RASC	SA	*Ranunculus sceleratus*	celery leaved buttercup	6.7	1.8	2	16.6	6.7	4
RUMA	MF	*Rumex maratimus*	golden dock	13.3	4.9	4	10.8	8.1	5
SASP	WO	*Salix* species	willow species	36.4	9.8	7	21.8	2.3	4
SCFE	SEM	*Scolachloa festucacea*	whitetop grass	35.1	11.6	5	23.8	4.0	2
SISU	SEM	*Sium suave*	water parsnip	9.6	2.1	3	15.3	6.0	7
SOAR	SM	*Sonchus arvensis*	sow thistle	26.5	21.3	7	19.6	13.4	7
SOSP	WP	*Solidago* species	goldenrod species	18.2	15.9	7	18.3	14.1	8
STPA	SM	*Stachys palustris*	marsh hedge-nettle	17.5	7.3	7	20.4	4.0	5
TAOF	WP	*Taraxacum officinale*	common dandelion	18.4	22.3	9	19.5	23.5	9
THAR	WP	*Thlaspi arvense*	pennycress	8.8	1.8	5	11.0	3.4	5
TRSP	UPL	*Trifolium* species	clover species	20.4	7.0	7	23.8	11.7	7
TYLA	DEM	*Typha latifolia*	common cattail	43.4	13.1	5	37.7	27.2	8
VIAM	UPL	*Vicia americana*	wild vetch	13.5	5.5	6	10.4	4.7	3

Table 2.3: Cover and frequency for common plant taxa observed in 6 restored and 6 natural wetlands in the northern Prairie Parkland of Saskatchewan. Common species were included in Correspondence Analysis (CA) and are defined as species that were observed in more than 2.5% of the quadrats sampled in each province. Canopy cover for each taxon was determined using the mean percent cover for all quadrats in which that plant was present on a given wetland. Frequency is defined as the number of observations of a plant species or genera as a percentage of the total number of quadrats sampled per wetland. Guild abbreviations are discussed within the text of the methods.

				NATURAL WETLAND			RESTORED WETLAND		
				64 species			62 species		
Code	**Guild**	**Scientific Name**	**Common Name**	**% COVER**	**% FREQ**	**# PONDS**	**% COVER**	**% FREQ**	**# PONDS**
AGSP	WP	*Agropyron* species	wheatgrass species	27.3	13.7	5	29.0	19.8	6
ALAE	SEM	*Alopecuris aequalis*	short awned foxtail	18.7	12.0	4	14.6	7.5	3
BESY	SEM	*Beckmania syzigachne*	sloughgrass	20.2	19.7	4	10.0	23.3	6
CAAT	SEM	*Carex atherodes*	slough sedge	46.7	31.7	6	45.9	44.9	6
CASP	SM	*Carex* species	sedge species	40.8	39.3	6	33.0	36.6	6
CIAR	SM	*Cirsium arvense*	Canada thistle	16.2	15.3	5	14.2	23.3	6
CIMA	SM	*Cicuta maculata*	water-hemlock	14.8	7.7	3	6.7	2.6	2
DAGL	WP	*Dactylis glomerata*	orchard grass	39.2	7.7	2	0.0	0.0	0
ELSP	SEM	*Eleocharis* species	spikerush	37.5	36.1	6	32.6	32.2	6
EQAR	SM	*Equisetum arvense*	common horsetail	23.4	15.8	5	20.5	18.9	4
ERGL	WP	*Erigeron glabellus*	smooth fleabane	8.2	4.4	3	13.8	4.4	3
GATR	SM	*Galium trifidum*	small bedstraw	17.4	3.8	2	8.8	1.8	2
GLPU	SM	*Glyceria pulchella*	graceful manna grass	23.1	16.4	5	23.1	1.8	6
HIVU	SA	*Hippuris vulgaris*	common mare's tail	15.8	5.5	4	17.3	4.4	2
JUBA	SM	*Juncus balticus*	wire rush	26.3	4.9	4	35.5	4.4	3
KOCR	UPL	*Koeleria cristata*	june grass	29.0	10.9	4	30.1	8.4	6
MEAR	SM	*Mentha arvensis*	wild mint	17.8	14.8	6	16.3	29.1	5
OPWA	OPWA	—	open water	52.8	55.7	6	44.9	50.2	6
PESA	SM	*Petasites sagittatus*	arrow-leaved colt's foot	25.0	5.5	3	30.0	1.3	1
PHAR	SEM	*Phalaris arundinacea*	reed canary grass	62.3	1.1	1	38.8	0.9	0
POAN	WP	*Potentilla anserina*	silverweed	12.5	8.2	3	13.6	4.0	3
POPA	SM	*Poa palustris*	fowl bluegrass	42.3	6.6	3	21.7	11.0	3
POPR	WP	*Poa pratense*	Kentucky bluegrass	25.0	5.5	4	24.5	2.2	2
POSP	WO	*Populus* species	poplar	43.5	2.7	1	14.6	2.6	3
RUMA	MF	*Rumex maritimus*	golden dock	13.9	6.6	2	15.7	4.8	2
RUSP	SM	*Rumex* species	dock species	0.0	0.0	0	13.3	6.6	1
SASP	WO	*Salix* species	willow species	26.8	9.8	4	32.5	12.8	6
SCFE	SEM	*Scolachloa festucacea*	whitetop grass	34.2	26.2	5	50.2	24.7	5
SCGA	SM	*Scutellaria galericulata*	marsh skullcap	27.3	6.6	2	0.0	0.0	0
SCLA	DEM	*Scirpus lacustris*	common great bulrush	12.2	9.3	5	11.5	13.7	5
SISU	SEM	*Sium suave*	water parsnip	14.6	10.4	4	13.5	11.5	3
SOAR	SM	*Sonchus arvensis*	sow thistle	26.2	27.3	6	19.3	24.2	6
SOSP	WP	*Solidago* species	goldenrod species	20.5	20.8	6	13.7	24.7	6
SPEU	SEM	*Sparangium eurycarpum*	giant bur-reed	26.3	9.8	2	0.0	0.0	0
SPOB	SM	*Sphenopholis obtusata*	prairie wedge grass	44.8	6.6	2	11.0	5.7	5
STPA	SM	*Stachys palustris*	marsh hedge-nettle	13.1	7.1	4	11.4	6.2	5
STSP	SM	*Stellaria* species	chickweed species	9.8	1.1	2	9.0	5.7	2
TAOF	WP	*Taraxacum officinale*	common dandelion	16.8	18.6	5	16.8	20.3	6
TRSP	UPL	*Trifolium* species	clover species	35.7	4.9	1	32.9	5.7	2
TYLA	DEM	*Typha latifolia*	common cattail	38.6	25.1	6	34.8	39.6	6
VIAM	UPL	*Vica american*	wild vetch	17.4	7.7	3	10.3	3.5	3

Table 2.4: A comparison of the mean percent cover and percent frequency for each guild between 9 restored and 9 natural wetlands in Alberta, and 6 restored and 6 natural wetlands in Saskatchewan using Mann-Whitney U (non-parametric) test. Both cover and frequency are mean values for 9 or 6 wetlands. Wetlands without plant taxa from a given guild are included as 0.

Guild	Wetland type	No. wetlands with taxa	% Cover	Standard deviation	Cover U-stat	p	% Frequency	Standard deviation	Freq. U-stat	p
Alberta										
Deep emergent marsh	Natural	6	20.8	26.4	26.5	0.21	12.8	17.8	22.5	0.11
	Restored	8	32.1	19.0			21.1	16.7		
Floating aquatics	Natural	6	19.3	20.5	40.5	1.00	29.0	23.5	34.5	0.59
	Restored	8	17.0	17.0			27.7	29.0		
Mudflat annuals	Natural	6	6.8	6.7	37.5	0.79	5.0	4.8	29	0.31
	Restored	7	6.9	5.9			9.7	9.4		
Open water	Natural	9	49.1	26.7	47	0.57	45.5	16.8	44	0.76
	Restored	9	42.8	19.2			44.7	20.5		
Submersed aquatics	Natural	6	20.6	28.4	36	0.69	8.6	13.1	33	0.50
	Restored	7	21.5	18.2			13.1	14.4		
Shallow emergent marsh	Natural	9	44.4	18.3	56	0.17	17.6	6.9	33	0.51
	Restored	9	32.3	11.1			21.2	7.7		
Sedge meadow	Natural	9	32.1	10.4	50	0.40	15.0	4.7	36	0.69
	Restored	9	27.3	8.4			16.2	6.7		
Upland	Natural	9	18.6	5.3	50	0.40	9.7	5.3	37	0.76
	Restored	9	17.4	5.8			9.3	3.7		
Woody vegetation	Natural	7	26.3	18.9	47	0.56	8.4	11.3	51	0.35
	Restored	5	21.0	23.3			3.6	3.9		
Wet prairie	Natural	9	25.1	11.0	34	0.57	14.2	4.7	42	0.90
	Restored	9	25.7	7.7			13.8	4.1		
Saskatchewan										
Deep emergent marsh	Natural	6	26.5	12.2	17	0.87	17.3	12.9	8	0.11
	Restored	6	27.8	11.7			28.6	9.8		
Floating aquatics	Natural	4	13.9	13.4	27	0.14	19.9	18.6	22.5	0.45
	Restored	3	3.1	4.0			9.7	14.7		
Mudflat annuals	Natural	2	4.0	6.1	12	0.32	3.6	6.1	11	0.25
	Restored	5	5.8	7.1			9.5	15.4		
Open water	Natural	6	50.6	24.5	23	0.42	56.4	9.1	26	0.20
	Restored	6	39.2	31.0			48.2	16.5		
Submersed aquatics	Natural	5	16.0	14.9	17.5	0.94	7.5	4.5	22.5	0.47
	Restored	5	16.4	9.7			5.4	4.8		
Shallow emergent marsh	Natural	6	31.0	9.9	14	0.52	27.2	8.4	17	0.87
	Restored	6	33.2	9.1			28.0	11.9		
Sedge meadow	Natural	6	24.9	10.4	19	0.87	17.1	4.6	15	0.63
	Restored	6	22.8	7.7			18.9	6.3		
Upland	Natural	6	23.6	8.4	18	1.00	16.4	8.3	29.5	0.07 *
	Restored	6	26.2	15.1			8.3	3.6		
Woody vegetation	Natural	4	15.2	16.6	11	0.26	9.7	10.7	15	0.63
	Restored	6	29.7	7.2			13.2	14.2		
Wet prairie	Natural	6	19.0	8.4	20	0.75	13.9	4.6	18	1.00
	Restored	6	19.8	7.8			15.1	6.6		

Table 2.5: Results of correspondance analysis (CA) applied to 18 wetlands (9 restored) with 42 plant species (including open water) in the PPR of Alberta. Rare species were downweighted in the analysis. Extremely rare species (observed in less than 2.5% of all quadrats sampled) were excluded prior to analysis.

	AXIS			
	1	2	3	Total Inertia
Eigenvalue	0.702	0.417	0.375	4.0942
Cummulative percent variance of species data	0.349	0.373	0.419	

Table 2.6: Results of correspondance analysis (CA) applied to 12 wetlands (6 restored) with 41 plant species (including open water) in the PPR of Saskatchewan. Rare species were downweighted in the analysis. Extremely rare species (observed in less than 2.5% of all quadrats sampled) were excluded prior to analysis.

	AXIS			
	1	2	3	Total Inertia
Eigenvalue	0.622	0.345	0.289	2.7916
Cummulative percent variance of species data	0.414	0.536	0.633	

Table 2.7: A comparison of guild species richness in restored and natural wetlands in the PPR of Alberta and Saskatchewan with a published species estimates from Galatowitsch (1993) that correlate with wetland "health" or adequate wetland quality. Rating is based on a potential range of species that would categorize a plant guild community as excellent (E), typical (T) and depauperate (D) wetland. Reference values are taken from Galatowitsch (1993). Guild abbreviations are included within the text of the methods.

	Mean number of species											
Guilds	DEM		FA		SA		SEM		SM		WP	
Alberta												
Natural	1.0	D	1	D	1.7	D	4.1	D	8.8	D	7.9	T
Restored	1.5	D	1	D	1.6	D	5.9	D	8.4	D	7.1	T
Saskatchewan												
Natural	2.5	T	1	D	2.6	D	5	D	11.2	D	6.7	T
Restored	2.2	T	1	D	1.6	D	5	D	11.5	D	5.7	T
Reference												
Excellent wetland	5+	E	6	E	11+	E	16+	E	31+	E	15+	E
Typical wetland	3-4	T	3-5	T	4-10	T	7-15	T	16-30	T	6-14	T
Depauperate wetland	1-2	D	1-2	D	1-3	D	1-6	D	1-15	D	1-5	D

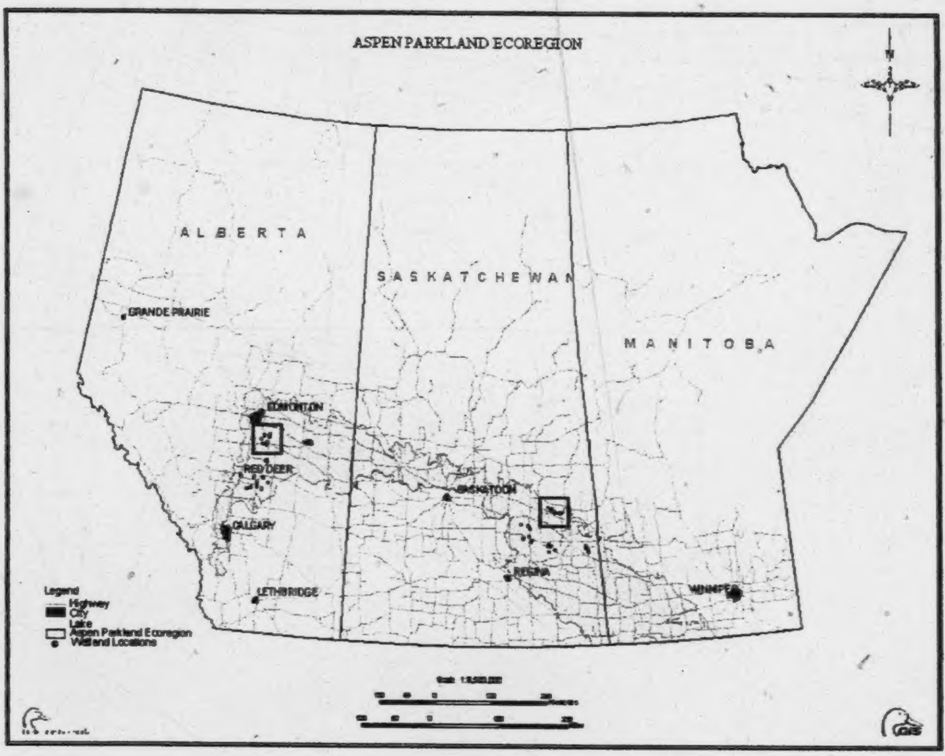

ASPEN PARKLAND ECOREGION
N
ALBERTA
SASKATCHEWAN
MANITOBA
GRANDE PRAIRIE
EDMONTON
RED DEER
CALGARY
LETHBRIDGE
SASKATOON
REGINA
WINNIPEG
Legend
Highway
City
Lake
Aspen Parkland Ecoregion
Wetland Locations

Figure 2.1: Location of restored and natural wetlands in the Aspen Parkland of Alberta and Saskatchewan. Boxes highlight the position of wetlands intensively sampled for vegetation and amphibians.

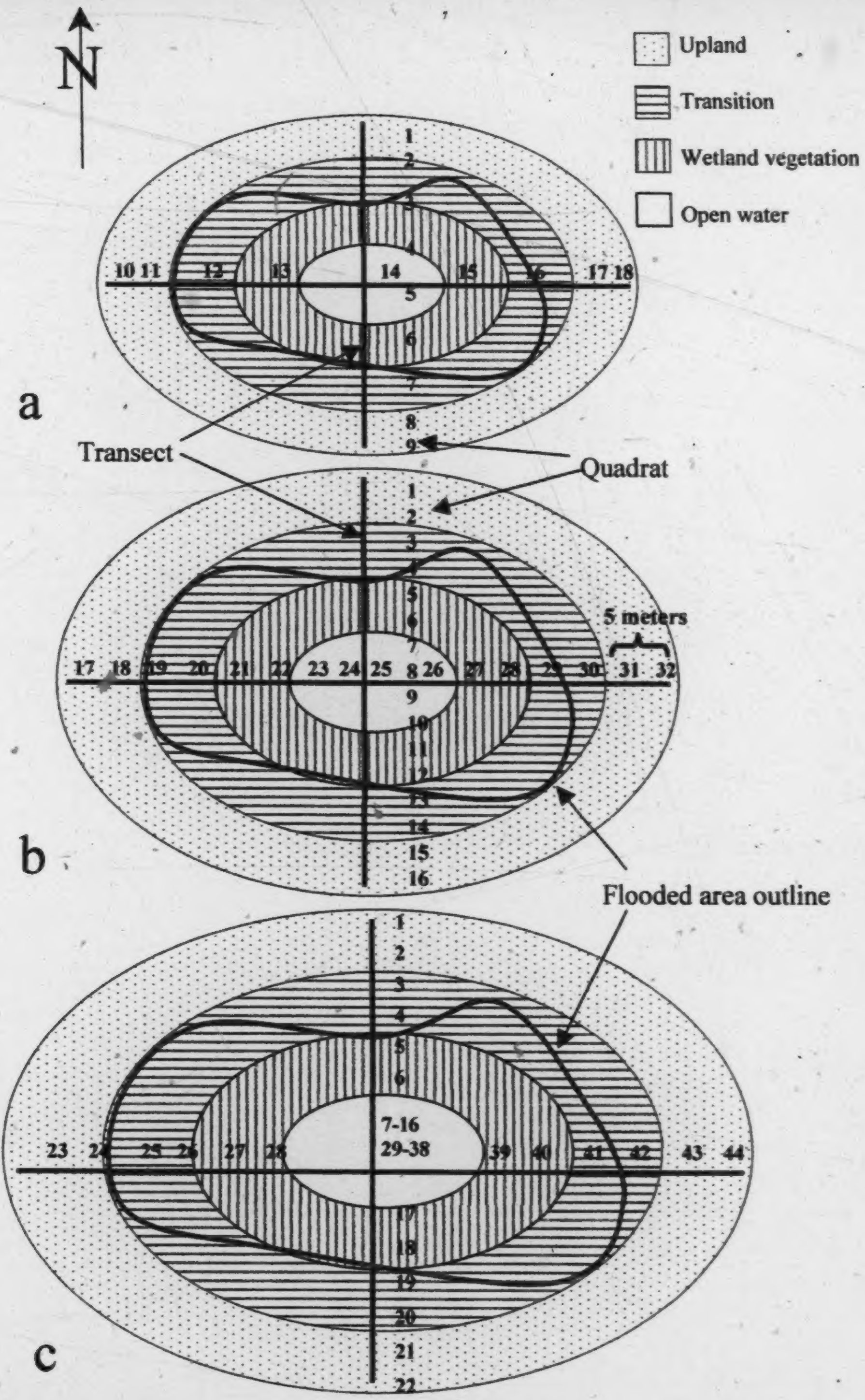

N
Upland
Transition
Wetland vegetation
Open water
a
1 2 3 4 14 5 6 7 8 9
10 11 12 13 15 16 17 18
Transect
Quadrat
b
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
5 meters
Flooded area outline
c
1 2 3 4 5 6 7-16 29-38 17 18 19 20 21 22
23 24 25 26 27 28 39 40 41 42 43 44

Figure 2.2: Wetland schematic illustrating the reorganization of quadrat data. Examples of a wetland with a. 22, b. 32, or c. 44 quadrats

Figure 2.3a: Correspondence Analysis (CA) ordination of 18 Alberta PPR wetlands (9 restored) based on 42 plant species (including open water).

Rare species were downweighted in analysis. There were 4 records for each wetland corresponding to different wetland zones (see legend). Open symbols indicate restored wetlands and closed symbols represent natural wetlands.

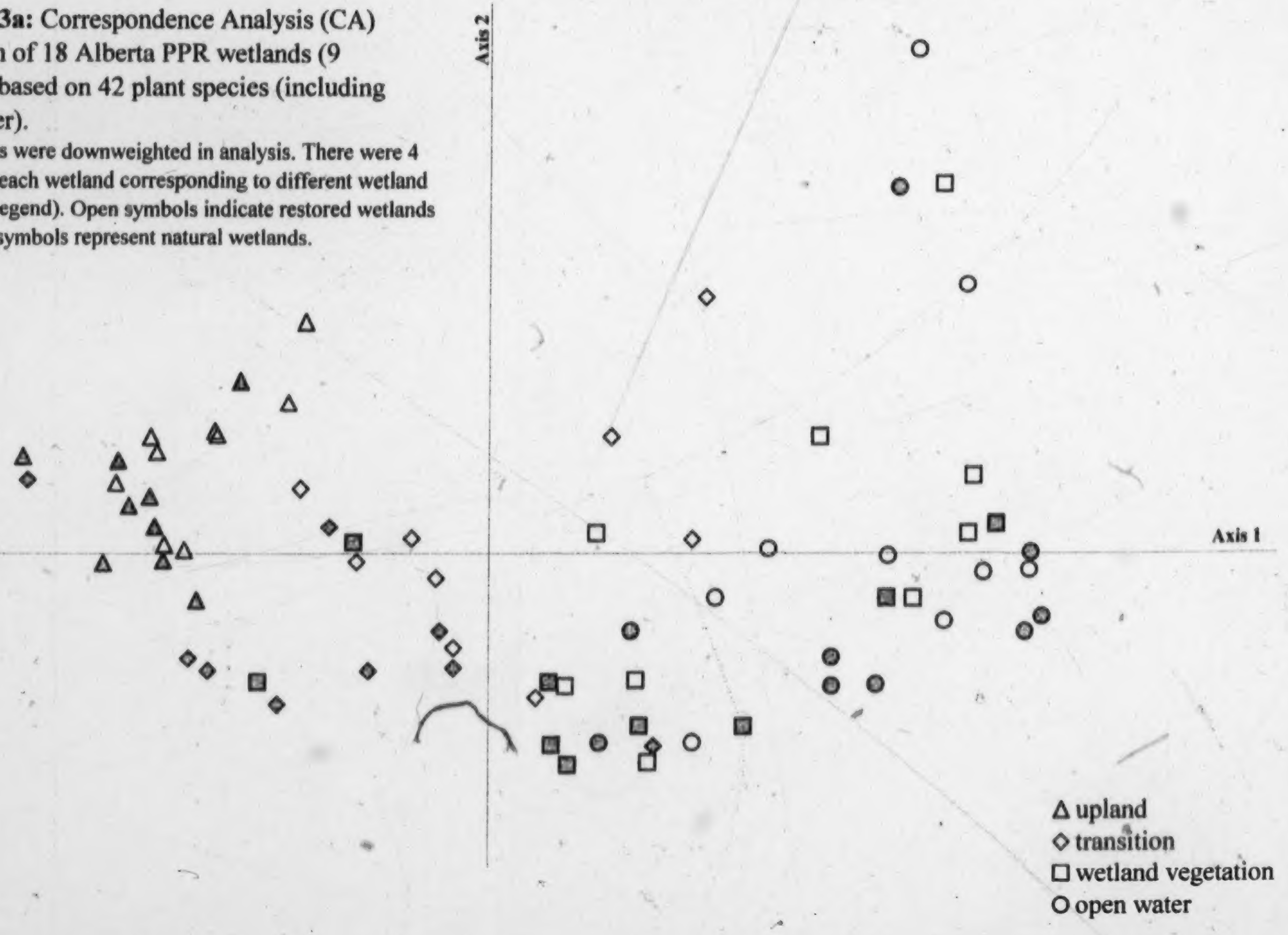
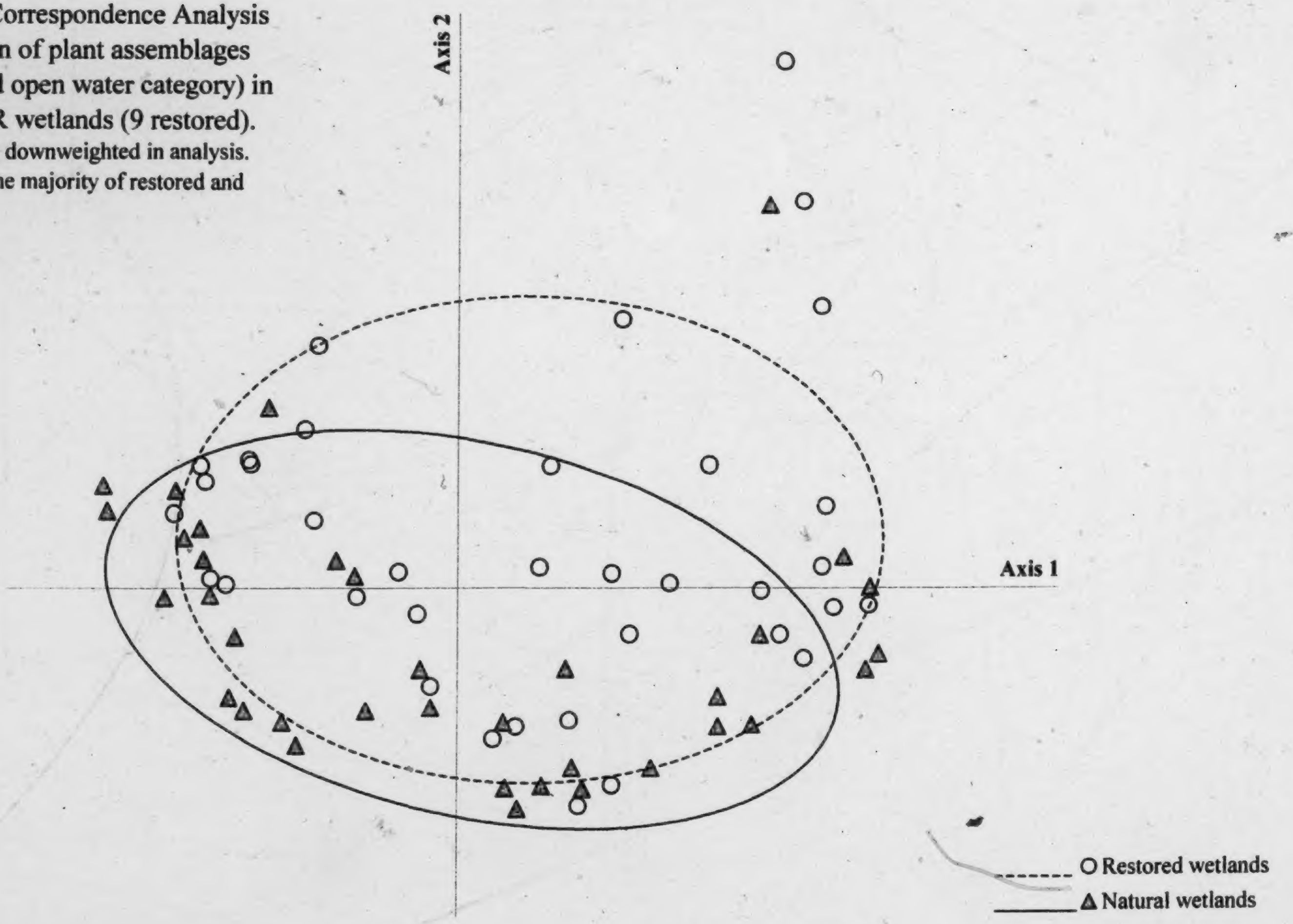


Figure 2.3b: Correspondence Analysis (CA) ordination of plant assemblages (41 species and open water category) in 18 Alberta PPR wetlands (9 restored). Rare species were downweighted in analysis. Ellipses enclose the majority of restored and natural wetlands.



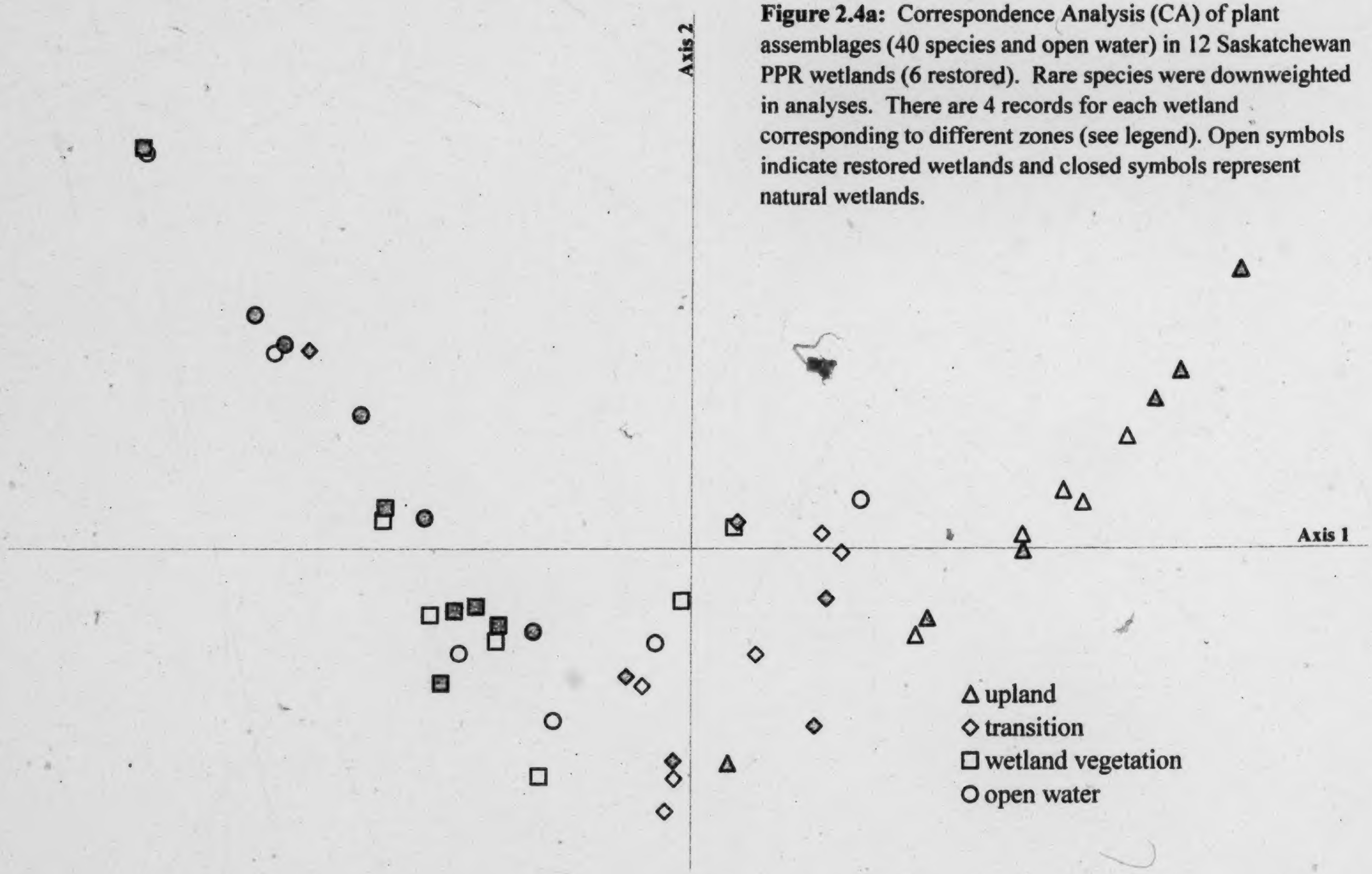
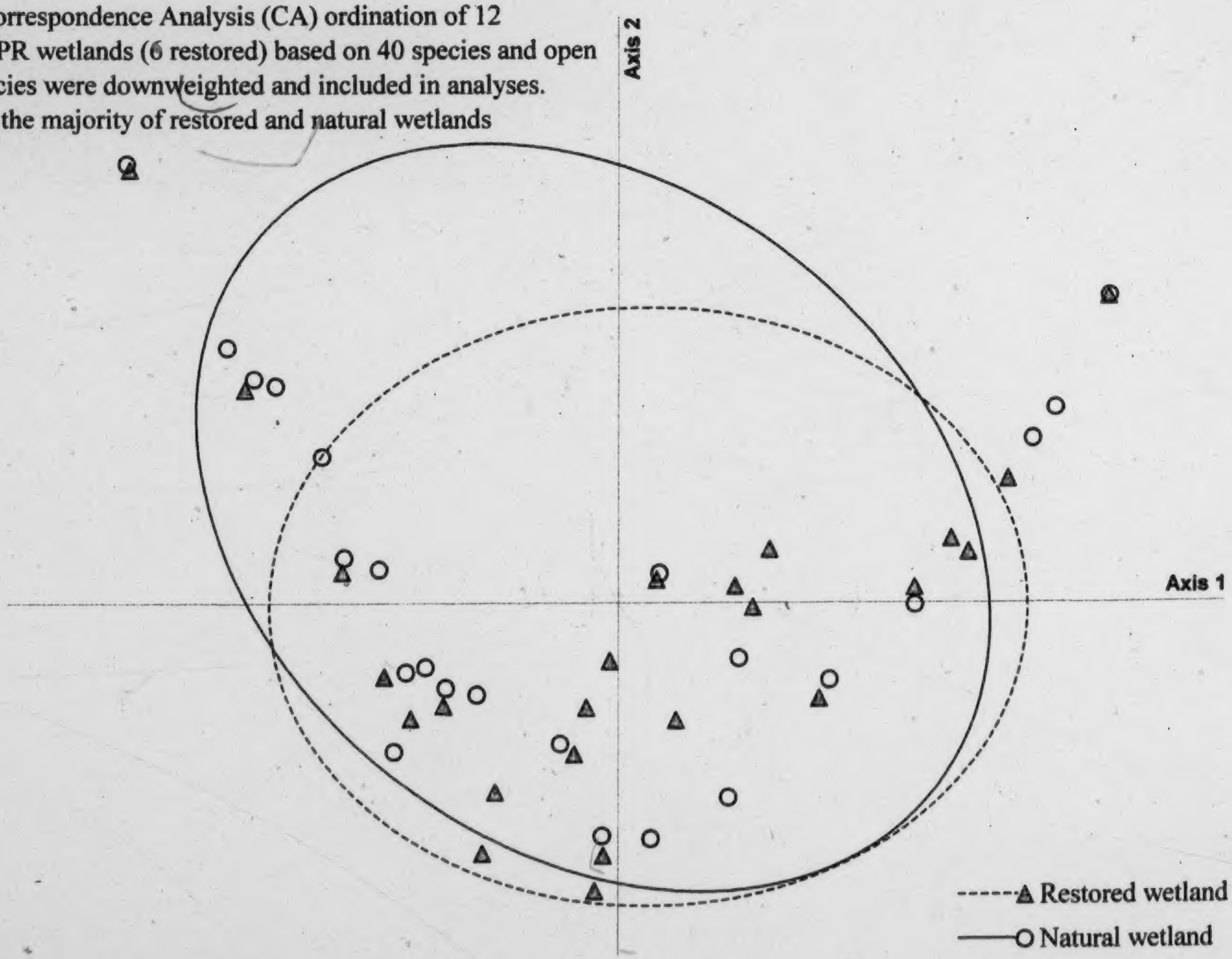


Figure 2.4a: Correspondence Analysis (CA) of plant assemblages (40 species and open water) in 12 Saskatchewan PPR wetlands (6 restored). Rare species were downweighted in analyses. There are 4 records for each wetland corresponding to different zones (see legend). Open symbols indicate restored wetlands and closed symbols represent natural wetlands.

Figure 2.4b: Correspondence Analysis (CA) ordination of 12 Saskatchewan PPR wetlands (6 restored) based on 40 species and open water. Rare species were downweighted and included in analyses. Ellipses enclose the majority of restored and natural wetlands



CHAPTER 3

RECOVERY OF BIRD ASSEMBLAGES IN RESTORED WETLANDS IN THE PRAIRIE POTHOLE REGION OF ALBERTA, CANADA

INTRODUCTION

Background

The Prairie Pothole Region (PPR) of central North America, which stretches over 780,000 km^2 (Mitsch and Gosselink 2000), is characterized by millions of small wetlands that were formed by glacial activity over 10,000 years ago (Galatowitsch and van der Valk 1994). A defining feature of the PPR is the physical heterogeneity of the wetlands; complexes are composed of basins of varying depths, sizes, duration of inundation and degrees of vegetative cover (Galatowitsch and van der Valk 1994). These wetlands provide critical habitat for wildlife (Batt et al. 1989, Kantrud, Krapu and Swanson 1989). Potholes provide breeding waterfowl with defensible pair isolation and resources sufficient for migration, courtship, brood rearing and molting (Batt et al. 1989, Swanson and Duebbert 1989). Over half of North American waterfowl production occurs in the PPR and this proportion can increase during good-water years. These wetlands are also important to a number of shorebirds, passerines, raptors and other bird species for food and cover during migration and nesting (Kantrud, Krapu and Swanson 1989, Weller 1999).

Wetlands are classified based on the presence of one or more zones with characteristic vegetation that reflects water permanence or duration of inundation (Stewart and Kantrud 1971). The vegetation zones (wetland class) in increasing permanence are as follows: low prairie (ephemeral, class I), wet meadow (temporary, class II), shallow emergent marsh (seasonal, class III), deep emergent marsh (semi-permanent, class IV) and open water (permanent, class V). The open water of a permanent (Class V) wetland (Stewart and Kantrud 1971) differs from the open water areas in Class III or IV wetlands. Class V wetlands lack extensive stands of emergent vegetation along the shoreline due to greater wind and wave action (Kantrud and Stewart 1984). This study focused on Class III and IV wetlands.

Over the last two centuries, the PPR became a center for crop and livestock production (Leitch 1989). For example, the primary agricultural region of Canada coincides with the principal waterfowl production area in North America (Lodge 1969). The northern one-third of the PPR is an eco-tonal zone between the true prairies to the south and the boreal forest to the north and is known as the Aspen Parkland (Bailey and Wroe 1974). The Aspen Parkland is distinguished from the grassland prairie by the presence of stands of *Populus* spp. in the uplands and surrounding wetlands interspersed with *Fescua* spp. grasslands (Walker and Coupland 1970). The Parkland once occupied 52,000 km^2 in Alberta (Moss 1932), but over 80% of the aspen parkland ecozone has been converted to agriculture or altered by grazing and urban development (Millar 1986 IN Turner et al. 1987, Rowe and Coupland 1984 IN Turner et al. 1987).

Attitudes, logistics and economics have made wetland drainage an integral component of agricultural development. Habitat loss and degradation is one of the most commonly cited reasons for the decline in species and population numbers (Huxel and Hastings 1999), and there are a disproportionate number of animals on North American endangered species lists that are wetland-dependent (Gibbs 2000). In the PPR, the loss of wetlands by widespread ditching has negatively impacted wildlife by degrading habitat

(Turner et al. 1987). Wetland loss is estimated at approximately 40% (Canada/United States Steering Committee 1986 IN Turner et al. 1987) throughout the PPR and as high as 70% near urban centers (Anonymous 1986) with more than 90% of those remaining wetlands adversely affected by agricultural expansion and urbanization (Neraasen and Nelson 1999).

As the majority of wetlands in this area have been drained using surface ditches, many sites have the potential for restoration (Galatowitsch and van der Valk 1994). Here, I define restoration as the return of a wetland from a disturbed or drained condition to its pre-existing hydrologic state, not specifically including the recovery of wetland function (Mitsch and Gosselink 2000, Gray et al. 1999). This can be accomplished by breaking tile drains, plugging drainage ditches using earth plugs, building dykes and constructing water control structures to effectively halt drainage (Galatowitsch and van der Valk 1994, Gray et al. 1999). Several studies report that re-flooding basins resulted in the unassisted recovery of emergent plant communities (Chapter 1, LaGrange and Dinsmore 1989, Sewell and Higgins 1991) from local soil seed banks (van der Valk and Davis 1978, van der Valk et al. 1992).

As part of an initiative to increase waterfowl populations, the North American Waterfowl Management Plan (NAWMP) has set goals to enhance habitat by restoring uplands and wetlands through the Prairie Habitat Joint Venture and Ducks Unlimited Canada (DUC)'s Alberta Prairie Care Program. Throughout the Canadian PPR, more than 900 wetlands have been restored, with almost 2000 ha re-flooded since 1989 (Gray et al. 1999). (Re)creation of wildlife habitat is often a goal of restoration and many managers agree that a healthy plant and animal community indicates an ecologically functional wetland (Gray et al. 1999). Several studies in the United States have investigated avian use of restored wetlands, but their findings have been equivocal and often lacked a direct comparison of restored wetlands to natural wetlands remaining in an area. To my knowledge, there have been no comparable Canadian studies, but anecdotal accounts from DUC staff suggest that wildlife in restored wetlands is comparable to that found in neighboring natural wetlands (Gray et al. 1999).

I collected information on the physical features, species richness, diversity, and community composition on restored (cease to be artificially drained) and natural (unaltered) wetlands in the Aspen Parkland of Alberta, Canada to address the following objectives:

1) To compare local physical features and landscape setting of restored and natural wetlands in the Aspen Parkland of Alberta.
2) To compare bird species richness and diversity in restored and natural wetlands.
3) To compare bird assemblage composition in restored and natural wetlands.
4) To investigate the relationship between local physical features and landscape setting of wetlands and the composition of bird assemblages.

The following sections review previous research findings and offer specific predictions related to the four objectives.

Habitat characteristics

If there are differences between restored and natural wetlands in local habitat characteristics, such as wetland area or size, maximum depth, the proportion of re-vegetation (ratio of open water to plant cover) and upland plant height, or landscape setting characteristics, such as the proportion of wetland or woodland in the surrounding area and distance to the next nearest wetland, this may translate into differences in bird assemblages. Few studies have directly compared the physical characteristics of restored wetlands with local natural, reference wetlands. Using these previous findings as a framework, I predicted that restored wetlands of similar area in Alberta would have similar depth (Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996a, Ratti et al. 2001) and similar cover provided by emergent plants (LaGrange and Dinsmore 1989, Sewell and Higgins 1991, Ratti et al. 2001), but would have reduced cover provided by wet meadow and low prairie plant guilds (e.g. *Solidago* spp., *Poa pratense*, see Table 2.2; Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996a, VanRees-Siewert and Dinsmore 1996, Brown 1999) and may be found in a landscape with less surrounding wetland area (Galatowitsch and van der Valk 1996a).

Species richness and diversity

Conclusions regarding bird species richness in restored wetlands have been equivocal. Although many studies have found comparable species richness and diversity in restored wetlands (LaGrange and Dinsmore 1989, Sewell and Higgins 1991, Ratti et al. 2001, VanRees-Siewert and Dinsmore 1996), several studies have made a connection between depauperate plant and invertebrate communities and lower bird species richness (Delphey and Dinsmore 1994, Brown and Smith 1998, Galatowitsch and van der Valk 1994, 1996a, 1996b). Therefore, I proposed that because of potential differences in vegetation between restored and natural wetlands, the richness and diversity of bird species would be reduced in restored wetlands.

Species Composition

The majority of avian studies have presented species lists or compared species richness, and few have specifically compared the community composition of restored and natural wetlands. I suggested that if my first two predictions hold, then bird species composition will differ between restored and natural wetlands, and more specifically that groups of birds that use the wet meadow and low prairie zones (e.g. wrens, *Cistothorus* spp., sora, American bittern, common yellowthroat; Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1994) would be reduced in abundance or absent in restored wetlands in Alberta. In order to compare species composition between restored and natural wetlands in the PPR, I chose to employ multivariate statistical techniques. Multivariate analyses make it possible to handle large data sets, allow the examination of multiple variables simultaneously and therefore, reflect the multidimensional nature of ecological systems (McGarigal et al. 2000). To my knowledge, these techniques have not been applied in assessing Prairie wetland restoration.

Species-environment relationship

The extent of habitat recovery is critical for wildlife use of restored wetlands. Many habitat characteristics have an influence on the distribution and abundance of bird species including the area of aquatic habitat (Brown and Dinsmore 1986, Kantrud and Stewart 1984, Tyser 1983, Naugle et al. 1999), wetland depth (Weller 1999, Stewart and Kantrud 1971), percent of a basin covered by different vegetation zones (Weller and Fredrickson 1974, Fairbairn and Dinsmore 2001b), the overall structure and cover pattern of vegetation (Murkin et al. 1997, Weller 1999, VanRees-Siewert and Dinsmore 1996), wetland shape and shoreline (Fairbairn and Dinsmore 2001a), water chemistry (Weller

1999), and landscape setting characteristics such as the proportion of surrounding cropland (Greenwood et al. 1995) or wetland (Brown and Dinsmore 1986, Fairbairn and Dinsmore 2001a), or wetland distribution patterns (Semlitsch and Bodie 1998, Naugle et al. 2001). Therefore, I expected to find differences in bird species richness and composition with changes in wetland area, depth and chemistry, and that species composition would reflect the patterns of wetland vegetation and cover, and landscape setting as these characteristics are related to individual species' habitat, home range and food resource needs.

My study evaluated the success of restoration by documenting avian use and characterizing local and landscape habitat characteristics in restored as compared to natural wetlands in the surrounding area. If habitat characteristics (such as wetland depth, vegetative cover, surrounding wetland area) are similar between restored and natural wetlands, it follows that similar bird species will be found in both wetland types. This investigation was part of a larger study of plant (Chapter 2), amphibian (Chapter 5) and avian communities in restored and natural wetlands of the Aspen Parkland of Alberta and Saskatchewan (Chapter 4). The Alberta and Saskatchewan study sites were greater than 800 km apart and provided the opportunity to compare habitat remediation techniques in 2 geographic locations within the same Ecoregion. The present chapter focuses on patterns of bird assemblages in Alberta. Restored wetlands in Saskatchewan displayed different patterns, and for this reason, I have chosen to present Saskatchewan results and geographic comparisons separately (Chapter 4).

METHODS

Study Area

A total of 102 wetlands were sampled in Alberta, Canada within the Aspen Parkland Ecoregion of the Prairie Pothole Region (PPR; Environment Canada 1996; Figure 3.1). In 1999, 72 wetlands (39 restored) were surveyed within 100 km of Camrose, Alberta. In 2000, 77 wetlands (39 restored) were surveyed in the same area. A sub-set of the wetlands surveyed in 1999 (47, 22 restored) was surveyed again in 2000 in order to assess inter-annual variation. Mean July temperatures in the Parkland range from 9.4° to 22.5 °C. In 1999, July temperatures ranged from 8.5° (minimum) to 20.2 °C (maximum taken from Edmonton, Alberta), and in 2000, the range was 2.6° to 15.3 °C (Environment Canada climate information 2000). Overall, the climate is harsh with a short growing season and low precipitation (mean total annual precipitation in Edmonton, Alberta = 466 mm; 1999 total precipitation=454.4 mm, 2000 total precipitation=388.9 mm Environment Canada 1996). Annual evaporation ranges from 444 – 510 mm in Alberta (Smith 1971).

Wetland Selection

All selected wetlands were small (<2 ha), seasonal (Class III) or semi-permanent (Class IV; Stewart and Kantrud 1971) located on DUC purchase or lease property with surrounding uplands of planted cover or native parkland. In the PPR, seasonal and semi-permanent wetlands are the most important for waterfowl and non-game bird species (Kantrud and Stewart 1977). All wetlands were fresh (<500 µS/cm) to slightly brackish (<2000µS/cm; Stewart and Kantrud 1971). Minimum distance between surveyed wetlands on the same property in a given year was 100 m. On average, surveyed wetlands were between 250 and 400 m apart, and there were 2-5 wetlands surveyed on a given property. Natural (46), relatively unaltered wetlands served as reference sites and were selected randomly from approximately over 100 wetlands of similar size and permanence located on DUC projects in the area. Restored wetlands (56) were randomly selected from a pool of more than 300 similarly sized restored wetlands in the area. Ditch plugs were constructed by DUC engineering staff 3 – 8 years (1992-1997) prior to my surveys and are representative of the company's restoration efforts in time and scale. Selected restored wetlands were at least 3 years post-restoration to allow time for potential re-vegetation. The majority of DUC staff report substantial re-vegetation 1-year post-restoration (Gray et al. 1999), and this pattern is supported by several studies (LaGrange and Dinsmore 1989, Sewell and Higgins 1991; Ratti et al. 2001). For construction details see Gray et al. (1999). The location of all surveyed wetlands was referenced within 20 m using GPS and recorded in Universal Transverse Mercator (UTM) coordinates (northing and easting). A list of surveyed wetlands is included in Appendix 2.

Habitat characteristics:

At the time of each bird survey, I collected parameters to describe local wetland habitat (listed in Table 3.1). Maximum wetland depth (cm, MNDPTH) was determined by walking transects through the wetlands, and recorded using a calibrated PVC pipe during wetland selection in 1999, and following each survey in 2000. Electrical conductivity or specific conductance (μS/cm, SQCOND) was measured using a YSI model 33 S-C-T conductivity meter or Corning model TDS 60 portable conductivity meter *in situ* at the time of each survey for each wetland in 2000, and once prior to surveys in 1999. Conductivity is highly correlated with water salinity (Wetzel 1983) and will serve as a proxy thereof. All wetlands were classified according to Stewart and Kantrud (1971). The proportion of the wetland with plant cover (MNBASIN) or inversely the amount of available open water habitat was recorded twice during the field season. As previous studies in the southern PPR found expected vegetation zones absent or reduced and because each zone reflects different vegetation structures, I documented the proportion of the basin covered by each zone (as indicated by characteristic plant species); low prairie (MNLOW), wet meadow (MNWET), shallow emergent marsh (MNSHAL), deep emergent marsh (MNDEEP). Following the point count, I estimated the height of surrounding upland vegetation approximately 20 m from the wetland edge in each cardinal direction (LOGUPHT). This will serve as a proxy for the quality of upland habitat, which is important for some upland-nesting wetland dependant bird species (e.g. dabbling ducks, northern harrier).

The landscape setting of each wetland was quantified by digitizing post-restoration air photos (1:30 000) obtained from DUC. Using Arcview 3.2 (ESRI 1992), major habitat types were identified in the area surrounding each surveyed wetland (the proportion within a 500 m radius) and quantified. Habitat types included woodland, wetland, cropland and upland. Woodland (AWOOD) was defined as habitat with woody vegetation (*Populus* spp., *Salix* spp., or conifers) with a vertical height >3 m. Wetland habitat (ATLWETL) included natural and restored basins of all sizes and classes. Cropland (ACROP) included areas that were tilled and planted to grain or row crops, as well as fields left to fallow. Upland (AUPLAND) included planted cover (a mixture of grasses planted for wildlife cover), native or naturalized grasslands, and pastures. The distance (m) to the next nearest patch of woodland (> 2ha, NNWOOD), wetland (of any size, NNWETL) and roadway (NNROAD) was also recorded. Wetland area (m^2, LOGAREA) and perimeter (m, PERIM) for each surveyed wetland was also obtained from the digitized air photos. The extent of the basin was defined by the transition from low prairie vegetation to planted cover. Using the metrics of area and perimeter, an index of wetland shape incorporating shoreline development was also calculated (SHAPE, McGarigal and Marks 1994).

Bird Surveys:

I surveyed selected wetlands for all bird species twice during the field season following the arrival of the majority of migratory birds. In 1999, wetlands were surveyed between May 23 and June 4 and a second time between June 18 and June 30. In 2000, wetlands were surveyed between May 21 and June 3 and again from June 18 to July 4. The order in which wetlands were surveyed was for the most part randomly determined. To reduce potential biases, investigator and time of survey were alternated between May and June surveys. Surveys were conducted between sunrise (~0500 hr) and 1000 hr in the absence of high winds (>30 km/hr), heavy rain, or thick fog. Each survey began approximately 100 m from the wetland edge (or from where wetland first became visible) in order to count waterfowl and other birds that commonly flush (fly away) upon the investigator's arrival (Bibby et al. 1992).

Following this initial survey, an 8-minute point count was conducted from a pre-determined station in the emergent vegetation of the wetland. It has been shown that although longer point counts produce more information, intervals >10 minutes are less efficient due to increased sampling error (Smith et al. 1998). Counting stations at each wetland were pre-determined by randomly selecting a cardinal direction from which the count would be conducted. All species heard or observed within a 50 m half-radius, including the immediately adjacent upland (Figure 3.2), were recorded during the 8-minute period. The location of a detected bird within the counting area was recorded as open water, wetland vegetation, upland, 'flying within the wetland', or 'flying over the point count area' (>50 m, "fly-over"). Birds that arrived at a wetland during a survey or were observed after were not included in analyses.

In order to solicit the calls of more secretive bird species (Virginia rails, Yellow rails, *Coturnicops noveboracensis*), call-response surveys were conducted following the point count (Gibbs and Melvin 1993, B. Dale, Canadian Wildlife Service, pers.commun.1999). Calls were played for 2 minutes: 30 sec Virginia rail, 30 sec silence, 30 sec Yellow rail, 30 sec silence.

DATA ANALYSES

All of the following analyses were conducted using presence/absence of species at a wetland to reduce uninformative variability within the data. All analyses were initially completed using bird species abundance (total number of individuals present), where appropriate results and patterns were identical. Presence includes bird species observed or heard at a wetland during the initial survey or point count and does not include fly-overs, incidental observations or species heard during call-response surveys. All bird species (including rare species) observed within or on each wetland were included as presence or absence in calculations of species richness and diversity. Bird species that were observed on <5% of all wetlands (or <5 wetlands total, i.e. rare species) were not included in community analyses (Gauch 1982).

Preliminary analyses

As wetlands were monitored over a 2-year period, preliminary analyses were conducted to determine inter-annual variation and explore combination of 2 years of data in further analyses. Bird species composition was compared between 1999 and 2000 for the 47 wetlands surveyed in both years using both Mantel (PCOrd 4.0, McCune and Mefford 1999) and PROTEST analysis (MSDOS program, Jackson 1995). Mantel tests evaluate the null hypothesis of no relationship between two matrices. The test was performed using Monte Carlo randomization (9999 permutations) and Sorenson or Bray-Curtis distance measurement, which was most appropriate for presence/absence data (McCune and Mefford 1999). As an additional evaluation of compositional similarity between years, PROTEST was also conducted comparing the first 3 correspondence analysis (CA) axes scores for 1999 versus 2000 for wetlands surveyed in both years. All bird species, including rare species, were used in analyses. Like the Mantel test, PROTEST uses randomization, but it is based on a procrustean matrix rotation to assess concordance, and thereby eliminates the variation associated with the selection of an appropriate distance measure (i.e. Sorenson distance used in Mantel test above). PROTEST is proposed to be more powerful than Mantel tests (Jackson and Harvey 1993, Peres-Neto and Jackson 2001).

Results indicated a strong concordance or similarity of the bird species composition in 47 wetlands between 1999 and 2000 (Mantel, r=0.105 (r= standardized Mantel statistic) p=0.046; PROTEST, r=0.8324, p=0.002). The p-value for each of these tests is the probability of a closer fit due to chance. There were 47 bird species observed in these 47 wetlands in both years. Any differences in composition were related to uncommon species that were observed on <3 wetlands. Based on the similarity, data were then combined into a set that incorporated all new and revisited wetlands surveyed in 2000 (77 wetlands, 39 restored) and wetlands that were surveyed only in 1999 (25 wetlands, 17 restored). For the 47 wetlands surveyed in both years, only the 2000 data was incorporated and a total of 102 wetlands (56 restored) were included in the following analyses.

Habitat characteristics

In order to observe potential differences in the physical and landscape features in restored and natural wetlands, analyses were first conducted on habitat characteristics directly. Prior to these direct analyses or to incorporating habitat characteristics in analyses of species-environment relationships, the distribution of individual variables was examined to determine if transformation was necessary (P-P plots against normal distribution, SPSS 10.1.0, SPSS, Inc.1999). Although a normal distribution is not necessary for inclusion in ordination techniques, it can reduce the effect of outliers on results (McGarigal et al. 2000). Habitat characteristics as well as their respective transformation are listed in Table 3.1. Upland height (LOGUPHT), wetland area (LOGAREA), wetland perimeter (PERIM), distance to nearest wetland (NNWETL), distance to nearest woodland (NNWOOD), and distance to nearest road (NNROAD) were log-transformed. The proportion of crop (ACROP), upland (AUPLAND), wetland (ATLWETL) and woodland (AWOOD) within 500 m (78.5 ha) were transformed using arcsin (Zar 1999). Conductivity (SQCOND) was transformed using square root. Wetland depth (MNDPTH), proportion of vegetative cover on the basin (MNBASIN), proportion of each wetland zone (deep emergent marsh (MNDEEP), shallow marsh

(MNSHAL), wet meadow (MNWET), low prairie (MNLOW)), as well as wetland shape (SHAPE, an index) were not transformed. Individual habitat characteristics were compared using t-tests (Zar 1999).

For transformed variables, Pearson correlation coefficients were calculated (SPSS 10.1, SPSS, Inc. 1999) to determine if any habitat characteristics were collinear. Due to strong correlations ($|r| \leq \pm 0.65$, $p<0.05$) with other variables, MNDEEP, PERIM, AUPLAND were not included in analyses of habitat characteristics or species-environment relationships.

To explore differences in habitat characteristics alone, an unconstrained ordination was conducted. Detrended Correspondence Analysis (DCA), conducted on the remaining 15 environmental variables, indicated that the length of the first axis gradient was <2.0, and that Principal Components Analysis (PCA) was appropriate (ter Braak and Smilauer 1998). The first 2 PCA axis scores were compared using MRPP to test similarity between the wetland types. Multi-Response Permutation Procedure (MRPP) is a non-parametric technique used to test the null hypothesis of no difference between *a priori* identified groups and is analogous to discriminate analysis.

Species richness and diversity

Species richness (S), or the total number of species (including rare species) observed during timed surveys, was calculated for each wetland and compared between wetland types (restored and natural) using t-tests. Bird species diversity was also calculated for each wetland using Shannon's diversity index (H) and its equitability measure (E_h), which were also compared statistically using t-tests (Zar 1999).

Species composition

In order to summarize and graphically represent patterns in bird assemblage composition between restored and natural wetlands, I conducted Correspondence Analysis (CA; PCOrd 4.0, McCune and Mefford 1999). CA summarizes community data by grouping similar sites and species along a series of orthogonal axes that represent recombinations of hypothetical environmental variables. By examining the first gradient length in a preliminary DCA (>2.0 on axis 1; ter Braak and Smilauer 1998), I determined CA was appropriate for this unimodal dataset. Initial interpretation of bird assemblage-environment relationships was explored by calculating correlation coefficients between CA axis scores and the habitat characteristics matrix. CA axis scores were used in MRPP (Zimmerman et al. 1985) with Euclidean distance measures to assess the difference between species composition in restored and natural wetlands.

For CA biplots, confidence ellipses were plotted using Systat 9.0 (SPSS Inc 1998) to graphically highlight the position of the majority of restored and natural wetlands. These ellipses are centered on means for restored and natural wetlands. The major axes and orientation of the ellipses are determined by the standard deviation and covariance for restored and natural wetland groups, respectively. The size of the ellipse is based on p=0.683 (SPPS Inc.1998).

To compare the stability in composition of bird species assemblages over 2 years, a Jaccard similarity coefficient (S_j) was calculated for each wetland surveyed in both years (47, 22 restored; Krebs 1989). Jaccard's coefficient is calculated using binary data on species occurrence at wetlands. The compositional similarity between years was compared between restored and natural wetlands using t-tests (Zar 1999, SPSS 10.1.0, SPSS, Inc. 1999).

Species-environment relationship

To test my prediction regarding a relationship between species richness and wetland area and depth, the slope of the regression lines for $\log_{10}$(species richness) against $\log_{10}$(wetland area) (LOGAREA) or wetland depth (MNDPTH) were tested using t-tests for comparing two slopes (Zar 1999). A significance level of 0.05 was used for this test.

In order to directly evaluate the relationship between bird species assemblages and wetland habitat characteristics, I conducted Canonical Correspondance Analysis (CCA), appropriate for unimodal data (CANOCO 4.0; ter Braak and Smilauer 1998). CCA was conducted using presence-absence data for 100 wetlands using intersample distance and Hill's scaling, suitable for ecological data with longer gradient lengths (McCune and Mefford 1998, ter Braak and Smilauer 1998) and no downweighting of 'rare' species. Due to the size of my study area and to be conservative, the location of each wetland (UTM coordinates) was included as a covariable in all constrained ordinations to account for geographic variation. CCA varies from CA in that the axes are linear combinations of the environmental data and therefore summarizes community data based on measured explanatory variables. To assess the importance of each habitat characteristic in explaining the patterns in bird assemblages, a forward selection procedure was used. The significance of environmental variables was tested using 1000 Monte Carlo permutations ($p \leq 0.05$ for variable inclusion). Therefore, a final ordination was conducted including significant variables and the significance of each ordination axis and the overall model was tested using 9999 Monte Carlo permutations (ter Braak and Smilauer 1998).

To assess the relative contribution of varying scales of habitat characteristics to patterns of species composition, I used a series of partial CCAs to partition the variation into local and landscape factors (Bocard et al. 1992). The selection of variables included in partitioning was based on the forward selection procedure used in the above CCA (evaluating species-environment relationships). As in CCA, wetland location (UTM coordinates) was included in these analyses as covariable.

RESULTS

Habitat characteristics

Of the 102 wetlands surveyed for bird species and local and landscape habitat characteristics, 55 wetlands (32 restored) were classified as semi-permanent (Class IV) and the remainder (47 wetlands, 24 restored) were classified as seasonal (Class III; Stewart and Kantrud 1971). Restored and natural wetlands were comparable in all habitat characteristics, including wetland area, wetland depth and conductivity (Table 3.1). Only one variable differed significantly, distance to nearest road was greater in restored wetlands (t=-2.844, df=100, p=0.005; Table 3.1). Further analyses (see species-environment relationship) indicated that this variable was not related to patterns in species composition. PCA analysis on 15 variables supported a strong similarity in physical environments (Figure 3.3). The first 3 axes combined explained 45.8% of the variation between wetlands (Table 3.2). Axis 1 corresponded strongly (positively) with pond characteristics [wetland depth (MNDPTH), wetland area (LOGAREA), conductivity (SQCOND)], and negatively with the proportion of vegetative cover on the basin (MNBASIN) (Table 3.2). Axis 2 correlated with upland landscape characteristics [positively with the proportion of surrounding woodland (AWOOD) and negatively with the distance to the nearest woodland patch (NNWOOD)]. Axis 3 correlated negatively with upland height (MNUPHT) and the proportion of surrounding cropland (ACROP) and positively with the proportion of surrounding wetland area (ATLWETL). None of the correlations with the third axis were $|r| \geq 0.65$. MRPP analysis indicated that restored and natural wetlands did not differ significantly in the combined suite of environmental variables (Figure 3.3; note overlapping confidence intervals; T=-0.82, p=0.17).

Species richness and diversity

A total of 51 bird species were observed or heard during surveys in 1999 and 2000. Thirty of these species were considered dependent on wetlands for part of their life cycle such as food or nesting (Table 3.3). Call-response surveys resulted in a single record of a Virginia rail in a natural wetland. The number of species per wetland (S) was similar between wetland types with a mean of 6.9 (±4.0, 0-17) in natural wetlands and 6.0 (±3.3, 1-13) in restored wetlands (95% confidence interval for the difference between the means=-0.53 – 2.32; t=1.24, df=100, p=0.22). Species diversity (H) and its corresponding equitability measure (E_h) were very similar in restored and natural wetlands ($H_{natural}$=1.54, $H_{restored}$=1.45, t=0.81, df=100, p=0.42; $E_{h\ natural}$=0.9, $E_{h\ restored}$=0.9, t=0.07, df=100, p=0.94).

Species composition

Two wetlands were eliminated from community analyses. I did not record any bird species on Loveseth 2B, a natural wetland, and recorded only a single northern harrier (a rare species) on Wik 3, a restored wetland. CA cannot be performed on datasets with sites with zero species. Both wetlands were small (<0.12 ha), Class III wetlands with little to no water (<20 cm) and no emergent vegetation.

Results of CA on 100 wetlands (55 restored) and 22 bird species highlighted the similarity in species composition in restored and natural wetlands (Figure 3.4, Table 3.4). Note the overlap of the 68.3% confidence ellipses. CA scores on the first 3 axes did not differ significantly between restored and natural wetlands (MRPP, T=-0.16, p=0.35). Scores on CA axis 1 (correlation r=0.63, eigenvalue = 0.44) were significantly positively correlated with wetland depth (MNDPTH). Axis 1 separated bird assemblages into groups with various levels of wetland dependence. Shallow wetlands (low axis 1 scores) were characterized by the presence of upland or low prairie nesting birds (e.g. Leconte's, Nelson's sharp-tailed and savannah sparrow), whereas deeper wetlands (high axis 1 scores) supported marsh generalists (e.g. ruddy duck, American coot) and wetland-dependent passerines (yellow-headed blackbird). Wetlands with positive axis 1 scores were also characterized by dabbling ducks. Wetland area (LOGAREA) was also correlated (r=0.48) with the first axis, but not as strongly as depth (MNDPTH, Table 3.4). It should be noted that area and maximum depth are somewhat collinear (r= 0.52). Vegetation-related habitat characteristics (MNSHAL, LOGUPHT, SHAPE) were weakly correlated with the second axis (Table 3.4). Wetlands with low scores on axis 2 attracted woody vegetation-associated passerines (clay-colored sparrow, song sparrow, yellow warbler, American crow).

Restored and natural wetlands had comparable Jaccard similarity coefficients between years ($\bar{x}_{natural}$=0.31 ± 0.17, 0.0-0.67; $\bar{x}_{restored}$=0.26 ± 0.12, 0.0-0.53). The species composition of restored and natural wetlands was equally stable between 1999 and 2000 (t=1.16, df=45, p=0.25).

Species-environment relationship

Log_{10} (species richness) in both wetland types was correlated with LOGAREA (Figure 3.5; natural $R^2=0.34$, slope=0.41; restored, $R^2=0.28$, slope=0.34) and MNDPTH (Figure 3.6; natural, $R^2=0.60$, slope=0.01; restored, $R^2=0.38$, slope=0.01). The relationship between species richness and LOGAREA and MNDPTH did not differ significantly between restored and natural wetlands (LOGAREA, t=0.40, df=98, p=0.65; MNDPTH, t=-0.10, df=98, p=0.85). The relationship between species richness and LOGAREA and MNDPTH was also evident in the species richness overlay on the CA biplot (Figure 3.7). Species richness increased along the first axis as larger, deeper wetlands supported greater numbers of species.

CCA serves to directly evaluate the relationship between bird assemblages and habitat characteristics. CCA results for bird assemblages were consistent with patterns from CA. The variables included in CCA using forward selection were MNDPTH, SHAPE, ATLWETL, and MNBASIN. The final ordination and axis 1 and 2 were significant ($p<0.05$) in explaining patterns of variation in the species and sites (Table 3.5). Axis 3 and 4 were approaching a level of significance with p=0.09 and p=0.06, respectively. The majority of the variation in species composition was taken into account by the first axis. As in CA, axis 1 was highly correlated with MNDPTH and the bird species were drawn out along that axis in similar fashion (diving ducks to upland birds species; ruddy duck to Leconte's sparrow). Wetlands with negative scores along axis 1 and 2 were characterized by dabbling ducks. Wetlands with more complex shorelines had positive axis 2 scores and were characterized by sedge-nesting species, such as sora. Smaller, shallower wetlands with positive axis 1 scores had greater vegetative cover (MNBASIN), whereas larger, deeper wetlands had less vegetative cover and a larger proportion of open water. Marsh generalists, American coot, yellow-headed blackbird, black tern and red-winged blackbird, were associated with deeper wetlands with greater emergent vegetation. Larger, deeper wetlands with an increase in the number of wetland-dependent bird species were also associated with an increase in the proportion of wetlands in the surrounding area (ATLWETL).

Overall, little of the variation in composition of bird assemblages was explained by the habitat characteristics measured (9.7%); the sum of all canonical eigenvalues was only 0.30 and total inertia (variation) was 3.14 (Table 3.5). There was, however, total overlap of restored and natural wetlands (Figure 3.8) in the CCA triplot indicating that although the metrics that I collected explained only a modest amount of the variation observed among wetlands, variation in bird assemblages was not related to the restoration history of the wetland.

Local factors included in variation partitioning were MNDPTH, SHAPE and MNBASIN. These had been included in the final CCA model. In order to include an equivalent number of landscape variables (3), ACROP and NNWETL were included with ATLWETL. ATLWETL was also part of the final CCA model. ACROP and NNWETL were the next 2 variables included using forward selection. Overall analyses, including MNDPTH, SHAPE, MNBASIN, ATLWETL, ACROP and NNWETL, explained 13% of the variation in species composition. The majority of this variation (62%) was explained by local habitat characteristics. Thirty-four percent of the variation could be ascribed to landscape habitat characteristics, and there was very little interaction or overlap between the effects of local and landscape factors (3.4%, Figure 3.9).

DISCUSSION

Habitat characteristics of restored wetlands in the Aspen Parkland of Alberta strongly resembled those of natural wetlands in the area. Although I had anticipated differences in vegetative cover and the proportion of surrounding wetland area, PCA on habitat characteristics supported by MRPP analyses, showed that wetlands were of similar area, depth, conductivity, vegetative cover, and landscape setting regardless of drainage history. Unlike other studies (Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996b) and my predictions, I observed all vegetative zones (including wet meadow and low prairie) expected in restored and natural wetlands of similar permanence and comparable size (Table 3.1). An intensive survey of vegetation in a sub-sample of these wetlands (18, 9 restored) also found a high degree of similarity in the plant communities in restored and natural wetlands (see Chapter 2).

It follows that with a similar abiotic setting and comparable vegetation that the avian assemblage did not differ significantly between wetland types. As my habitat predictions were not supported, neither were my predictions of differences in species richness among restored and natural wetlands. Bird species richness, diversity, and abundance (equitability) were not significantly different among wetlands with different drainage histories. I found the mean number of species per natural wetland (S) was 6.9 and 6.0 per restored wetlands and that mean species diversity (H) was 1.54 in natural wetlands and 1.45 in restored wetlands.

Species richness was comparable to values for similarly sized natural wetlands (2.1 ha, S=7.3-8.6, Delphey and Dinsmore 1993) and restored wetlands (wetland area=1.4-3.0 ha, S=5-9, LaGrange and Dinsmore 1989; 2.6-3 ha, S=3.5-7, Hemesath and Dinsmore

1993) in Iowa. Ratti et al. (2001) documented an average species richness of 7.9 in natural (19.5 ha) and 8.4 in restored (22.6 ha) wetlands in North and South Dakota. Delphey and Dinsmore (1993) had found reduced species richness in restored wetlands (2.2 ha, S=3.6-5.4), but this was not corroborated by the present study. I observed lower species richness than in wetlands 1-4 years post-restoration in Iowa that had species richness comparable to natural Iowa wetlands (0.42 – 5.91 ha, S=10-13, VanRees-Siewert and Dinsmore 1996) in Iowa. However, these wetlands, as well as the wetlands surveyed in the Dakotas (Ratti et al. 2001), were larger than the wetlands of the present study.

Species diversity in Alberta wetlands was also considerably lower than in wetlands of the southern PPR ($H_{natural}$=3.0, $H_{restored}$=3.1, Ratti et al. 2001), but again the wetlands of Ratti et al. (2001)'s study were large, the total number of species observed was considerably higher (108 species versus 51 species in this study), and survey techniques were different. It can be noted that the grassland species pool in Alberta (216) is only slightly lower than that of Iowa (225) or the Dakotas (242, Birds of North America, Thayer Birding software Version 2.5)

The majority of species that I recorded (59%) were wetland-dependent species that rely on flooded basins for feeding or nesting (DUC unpublished data, Table 3.3). Commonly occurring wetland species (observed in >20% of wetlands) included red-winged blackbird, blue-winged teal, northern shoveler, mallard, American coot and sora. These are abundant species in the PPR and common nesters in Class III and IV wetlands (Kantrud and Stewart 1984, Galatowitsch and van der Valk 1994). Savannah sparrow (90% of wetlands) and clay-colored sparrow (69%) were ubiquitous species that, like the other sparrows encountered (LeConte's sparrow 47%, song sparrow 21%, Nelson's sharp-tailed sparrow 6%) cannot be considered obligate wetland breeders, but do have moderate associations with water bodies and wetlands (Ehrlich et al. 1988). Savannah sparrow, LeConte's sparrow, and Nelson's sharp-tailed sparrow, in particular, are known to nest in wet meadow and low prairie vegetation of pothole wetlands (Galatowitsch and van der Valk 1994, Ehrlich et al. 1988) and are frequently observed near wetlands.

Species that were unique to restored or natural wetlands were observed on fewer than 3 wetlands. In fact, aside from black-capped chickadee in natural wetlands (3), lesser yellowlegs (3) and Wilson's phalarope (3) on restored wetlands, all unique species were observed on only a single wetland. Species that were observed in only one wetland type can be categorized as 1) having a weak association with wetlands (black-capped chickadee, gray catbird, house wren, northern oriole), 2) more common in Class V (permanent) wetlands and mudflats (lesser yellowlegs, ring-billed gull), 3) or at the edge of their range (bobolink, northern harrier). Bufflehead was likely uncommon in the surveyed wetlands due to a substantial distance from appropriate woodland nesting habitat ($\bar{x}_{natural}$=234.4 m, $\bar{x}_{restored}$=172.6 m)(Ehrlich et al. 1988). Other unique species (American wigeon, barn swallow and marsh wren), although not necessarily uncommon in the area, appeared to be locally absent from the small wetlands surveyed (Fisher and Acorn 1998).

Early morning call-response surveys for Virginia and yellow rails were not successful. Both the time of survey and the rarity of these species in the area undoubtedly contributed to the lack of response and occurrence. A recent study by Environment Canada/Canadian Wildlife Service found that midnight surveys were more successful but still reported few occurrences of these species within Alberta (M. Norton, pers. commun. 2001).

The similarity in species composition between restored and natural wetlands was supported by ordination results (CA, CCA) and other statistical analyses (MRPP). My predictions regarding differences in species composition, in particular a reduced abundance of species that use the wet meadow and low prairie zone, were not realized. Wet meadow and low prairie nesting species, such as common yellowthroat, sora, and common snipe, were found in restored wetlands in equal or greater frequency than natural wetlands (Table 3.3). Species composition was equally stable between 2 years in natural and restored wetlands. Prairie pothole wetlands are dynamic systems subject to a fluctuating water regime caused by the variability of the prairie climate (Kantrud, Millar and van der Valk 1989) and this cycle affects the primary and secondary production, vegetation composition and distribution, and animal use of individual wetlands (Murkin et al. 2000). Although restored wetlands represent relatively new habitats, annual turnover due to (re)colonization is no greater than the changes in species composition among natural wetlands between seasons and years.

I found that bird assemblage composition was not determined by drainage history, but rather by local (wetland depth, wetland shape and proportion of vegetation cover on the basin) and to a lesser degree by landscape (proportion of wetland habitat within 500 m) habitat features. As I had found in previous studies (Brown and Dinsmore 1986, Kantrud and Stewart 1984, Tyser 1983, Paszkowski and Tonn 2000, Riffell et al. 2001, VanRees-Siewert and Dinsmore 1996), the relationships between species richness and composition, and wetland area and depth were especially strong. Larger, deeper wetlands supported a greater number of species. Conductivity in wetlands did not appear to play a strong role in predicting avian species composition. I had correctly predicted a connection between individual species needs and vegetation cover patterns and/or landscape patterns such as the surrounding wetland area. Species composition patterns and the importance of local vegetation structure (MNBASIN, SHAPE) reflected the habitat diversity of prairie wetlands as the vegetation changes with wetland depth (Weller and Fredrickson 1974). The deepest wetlands with the greatest proportion of open water provided the habitat used by ruddy ducks. Marsh generalists (e.g.: American coot or red-winged blackbird) that use emergent vegetation for nesting responded to longer shorelines and increased wetland density. Dabbling ducks were found in wetlands of moderate depth, larger in wetland area, and with moderate emergent vegetation. Passerines that nest in the low prairie or surrounding uplands (including nearby woodlands) were predominant in the shallowest, less permanent wetlands.

The majority of the variation in bird species composition appears to be attributed to local rather than landscape habitat characteristics in Class III and IV wetlands. Bird species vary in area sensitivity and habitat area requirements (Naugle et al. 1999, 2001, Fairbairn and Dinsmore 2001a, Galatowitsch and van der Valk 1994, Weller 1999). The small size of wetlands surveyed in this study may have precluded use by species with larger area requirements (Brown and Dinsmore 1986). Black tern, for the most part a marsh generalist, is a wide-ranging species that can be sensitive to the proportion of surrounding wetland area (Naugle et al. 1999). Although black tern was fairly common in wetlands surveyed, it was found primarily in larger wetlands in a landscape with a high density of wetland. Other species that are proposed to be area-sensitive were found in low frequency in the wetlands surveyed: willet, northern harrier (Galatowitsch and van der Valk 1994), Canada goose, pied-billed grebe (Brown and Dinsmore 1986), and northern pintail (Naugle et al. 2001). I documented bird assemblages that were dominated by common PPR species that are not area-sensitive and occur frequently in wetlands of a variety of sizes.

Why were restored wetlands in Alberta successful at recovering their bird assemblages, when sites from the southern reaches of the PPR did not? As discussed previously, the successful recovery of wildlife is critically linked to successful revegetation and habitat recovery. Vegetation plays an important role in wetland selection and use by birds (Weller and Fredrickson 1974). Birds appear to assess the structural features of a wetland as an indication of the quality of available resources, such as food and cover (Weller 1999). The successful restoration of plant communities in the Aspen Parkland documented by this study, as compared to sites in the southern PPR is related to the drainage history of northern wetlands. Wetlands in Iowa, for example, have been drained for a longer period of time (50 versus 10 years), often with a more efficient drainage technique (tile versus surface ditches), combined with a lower regional density of remaining natural wetlands (Galatowitsch and van der Valk 1994, 1996a, Gray et al. 1999). Climatic differences, specifically more predictable precipitation and reduced evaporation, may also increase the probability of successful restoration in the Aspen Parkland. My results from extensive community analyses were consistent with basic patterns reported by Ratti et al. (2001) in wetlands in the Dakotas.

I propose that the restoration of PPR wetlands in Alberta has successfully (re)created bird habitat for Class III and IV wetlands. Without a history of bird use in a drained wetland, basins prior to drainage and restoration, or grassland bird species use during low water years, I cannot conclude whether or not habitat was created, recreated or maintained. There is a great deal of general controversy over the 'success' of ecological restoration (Young 1996, Malakoff 1998, Ehrenfeld 2000) and the criteria that should be used to determine if restoration mitigates wetland loss (Mitsch and Wilson 1996). 'Failure' of restored and created wetlands has been attributed to a range of circumstances from a complete lack of re-flooding (Galatowitsch and van der Valk 1994) to the lack of use by a targeted endangered species (Malakoff 1998). Any reflooded wetland could arguably provide more habitat for wetland dependant wildlife than the alternative of no wetland at all (Adamus 1988, Gray et al. 1999). The comparative design of studies such as ours provides a common gauge for assessing restoration success (Mitsch and Wilson 1996, Delphey and Dinsmore 1993, Ratti et al. 2001).

Mitsch and Wilson (1996) propose 3 requirements for effective evaluation of restoration. The first is that a reflooded wetland needs time to recover communities and function before success or failure is determined. Shortly following restoration (< 5 years), we will only have learned the general trajectory of wetland development and even less concerning the wetland's function. Because of the slow development of ecosystems and the slow process of recruitment and growth of many organisms, at least 20 years should be allowed before a restoration's success is judged (Mitsch and Wilson 1996). The wetlands of this study were 3-8 years post-restoration, and so I recommend continued monitoring of restored wetlands to confirm success. To the extent that time and money permit, early morning point counts by a trained observer (see Methods, Bibby et al. 1992 or Galatowitsch and van der Valk 1994) should be periodically conducted each breeding season. Minimally, any visits to restorations to monitor physical works, should included a record of bird species present and vegetative cover.

The second criterion for successful evaluation of restoration involves the concept of self-design (Mitsch and Wilson 1996, Mitsch et al. 1998), i.e. allowing a system to select the best plant and animal assemblages for the existing conditions from artificially introduced species pools or natural colonization. Mitsch and Wilson (1996) warn that determining success based on the successful establishment of desired and actively introduced species may increase the likelihood of judging the restoration a failure. The self-design approach was practiced in restoring the PPR wetlands in my study, and resulted in plant and avian communities comparable to natural wetlands.

The third criterion to improve the likelihood of success is an understanding of wetland function (Mitsch and Wilson 1996). Loss of habitat involves changes in species and ecosystem function and restoration is as complicated as the changes accompanying lost habitat (Zedler 2000). Understanding of wetland hydrology and function (e.g. nutrient cycling, primary or secondary productivity) is necessary, as is the incorporation of this knowledge into the physical practice and planning of restorations. The process of restoration provides the opportunity to test ecological theories (Zedler 2000) and researchers should continue to work with managers to further the science of restoration.

In addition to my recommendations for long-term monitoring, managers should focus on restoring wetlands of a variety of sizes and classes in order to address the resource needs of the greatest number of species. Several studies have documented increased bird species diversity in large wetlands (Brown and Dinsmore 1986, VanRees-Siewert and Dinsmore 1993), but the importance of total surrounding wetland area and large-scale habitat heterogeneity should not be under-estimated (Fairbairn and Dinsmore 2001a, b; Naugle et al. 1999; Kantrud and Stewart 1984; Brown and Dinsmore 1986). Small wetlands (< 2-5 ha), in particular, are easily drained using modern equipment (Gray et al. 1999) and are not protected under current wetland management policies (Gibbs 1993, Semlitsch and Bodie 1998, Gibbs 2000, Murkin pers. commun. 2001). Analysis of the frequency of occurrence and the combined area of small wetlands in landscapes highlights their importance in the total wetland base (most wetlands are small) and connectivity of habitats (distance between adjacent wetlands; Gibbs 1993, Semlitsch and Bodie 1998, Gibbs 2000).

Comparison of historical and current distribution of wetlands with respect to size and permanence should be conducted across landscapes subjected to management or restoration. Galatowitsch (1993) reported that Class I and II wetlands (Stewart and Kantrud 1971) were under-represented compared to their pre-drainage extent. In order to restore wetland diversity, historical distributions should be investigated using soil surveys (Galatowitsch 1993), macroinvertebrate remains (Euliss et al. 2001), remnant plant seed banks (van der Valk et al. 1992), airphotos and/or historical data (verbal accounts and legal records).

Individual managers must take into account unique wetland habitats and the needs of individual species of concern. When resources are limited, managers should keep in mind the spatial context of potential restoration sites. The amount of time required for successful re-colonization of plants or birds is related to the proximity of wetlands to other source populations (Huxel and Hastings 1999).

Future research priorities in the PPR of Canada should include assessment of breeding success for birds nesting in restored wetlands. Nesting birds can be surveyed using a variety of search methods, including beat-outs or ATV drags (see Klett et al. 1986). This study did not examine Class I and II wetlands and a similar assessment of current levels of success in restoring these wetland types is recommended.

Summary

Restoration of prairie pothole wetlands is an effective mitigation technique in the effort to combat wetland loss. In central Alberta, differences in bird species diversity and community composition among wetlands was related to wetland depth, shape, vegetative cover and surrounding wetland area, not drainage history. Restoration of Class III and IV wetlands should continue to play an important role in future wetland conservation strategies in Prairie Canada.

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Table 3.1: Local and landscape features of 56 restored and 46 natural wetlands near Camrose, Alberta sampled in May - June 1999, 2000. Variables marked by * were included in PCA and CCA analyses. Only distance to nearest roadway was significantly different between restored and natural wetlands. (t=-1.381, df=100, p<0.05). Variables marked with $^{\bar{x}}$ are values based on means. Landscape habitat types are described in text. N/a indicates that no transformation was required.

ENVIRONMENTAL VARIABLE		Abbreviation	UNIT OF MEASURE	NATURAL WETLANDS Mean	NATURAL WETLANDS Range	RESTORED WETLANDS Mean	RESTORED WETLANDS Range	Variable transformation for ordination
LOCAL:								
wetland area	*	LOGAREA	m^2	2068.3	(404.9-6882.6)	1847.2	(202.4-7692.3)	log
wetland perimeter		PERIM	m	200.6	(64.0-1280.0)	160.6	(48.0-352.0)	n/a
shape index	*	SHAPE	-	1.2	(1.0-1.5)	1.2	(1.0-1.8)	n/a
maximum wetland depth	$^{\bar{x}}$ *	MNDPTH	cm	30.7	(0.0-86.5)	30.0	(0.0-88.0)	n/a
conductivity	$^{\bar{x}}$ *	SQCOND	µS/cm	675.8	(0.0-2000.0)	488.4	(0.0-2000.0)	square root
proportion of vegetative cover on basin	$^{\bar{x}}$ *	MNBASIN	%	71.5	(5.0-100.0)	66.1	(7.5-100.0)	n/a
proportion of deep marsh vegetation	$^{\bar{x}}$	MNDEEP	%	29.3	(0.0-90.0)	33.5	(0.0-95.0)	n/a
proportion of low prairie vegetation	$^{\bar{x}}$ *	MNLOW	%	7.4	(0.0-25.0)	9.3	(2.5-50.0)	n/a
proportion of shallow marsh vegetation	$^{\bar{x}}$ *	MNSHAL	%	51.7	(0.0-92.5)	48.5	(0.0-92.5)	n/a
proportion of wet meadow vegetation	$^{\bar{x}}$ *	MNWET	%	9.4	(0.0-45.0)	7.9	(0.0-47.5)	n/a
upland height within 20 m of wetland	$^{\bar{x}}$ *	LOGUPHT	cm	53.1	(5.0-172.5)	59.5	(23.8-537.5)	log
LANDSCAPE:								
Proportion of habitat type within 500 m of surveyed wetland								
cropland	*	ACROP	%	19.6	(0.0-80.2)	23.6	(3.7-81.4)	arcsin
wetland	*	ATLWETL	%	10.3	(4.3-20.5)	12.3	(1.7-28.3)	arcsin
upland		AUPLAND	%	43.0	(13.6-71.8)	41.8	(9.6-77.6)	arcsin
woodland	*	AWOOD	%	10.5	(0.4-43.0)	9.1	(0.0-40.2)	arcsin
Next nearest habitat patch								
woodland	*	NNWOOD	m	172.6	(6.0-957.0)	234.4	(0.0-1289.0)	log
road	*	NNROAD	m	296.9	(35.0-700.0)	413.4	(8.0-1076.0)	log
wetland	*	NNWETL	m	52.8	(6.0-136.0)	54.9	(11.0-302.0)	log

Table 3.2: Results of PCA for 15 habitat characteristics in 102 wetlands (56 restored) in Alberta and correlations between the habitat characteristics and scores from the first 3 axes of the PCA.
* indicates significance at $p<0.05$; ** indicates $p<0.01$.

	AX1		AX2		AX3	
Eigenvalue	3.07		2.13		1.68	
%variance	20.44		14.21		11.20	
Cummulative % variance	20.44		34.65		45.84	
Habitat characteristics						
SHAPE	0.26	**	-0.22	*	0.30	**
LOGAREA	0.75	**	0.00		-0.05	
MNBASIN	-0.67	**	-0.24	*	0.08	
LOGUPHT	-0.03		-0.02		-0.61	**
SQCOND	0.75	**	-0.18		-0.21	*
MNDPTH	0.85	**	0.22	*	-0.13	
MNLOW	-0.45	**	-0.14		0.38	**
MNSHAL	-0.56	**	-0.01		-0.43	**
MNWET	-0.35	**	0.07		-0.28	**
NNROAD	-0.06		0.17		0.15	
NNWETL	-0.15		0.52	**	-0.15	
NNWOOD	0.01		-0.79	**	0.14	
AWOOD	-0.09		0.81	**	0.13	
ACROP	0.01		-0.54	**	-0.58	**
ATLWETL	0.16		-0.22	*	0.57	**

Table 3.3: Avian species observed in restored (56) and natural (46) wetlands in the Prairie Parkland near Camrose, Alberta, Canada. * indicates wetland dependant species as defined by Ducks Unlimited Canada (unpubl). ^{r} indicates species considered rare (observed in < 5 wetlands total) that not included in community analyses. Code represents abbreviation used in figures.

					Documented presence in X number of wetlands	
CODE			**Common Name**	**Genus species**	**natural wetlands (46)**	**restored wetlands (56)**
ALFL		*	Alder flycatcher	*Empidonax alnorum*	5	2
AMCO		*	American coot	*Fulica americana*	11	10
AMCR			American crow	*Corvus brachyrhynchos*	5	4
AMGO	^{r}		American goldfinch	*Carduelis tristas*	3	1
AMRO	^{r}		American robin	*Turdus migratorius*	2	1
AMWI	^{r}	*	American wigeon	*Anas americana*	1	0
BASW	^{r}	*	Barn swallow	*Hirundo rustica*	1	0
BCCH	^{r}		Black-capped chickadee	*Poecile atricapillus*	3	0
BLMA	^{r}		Black-billed magpie	*Pica pica*	3	2
BLTE		*	Black tern	*Chlidonias niger*	4	3
BOBO	^{r}		Bobolink	*Dolichonynx oryzivorus*	0	1
BHCO	^{r}		Brown-headed cowbird	*Molothrus ater*	0	1
BUFF	^{r}	*	Bufflehead	*Bucephala albeola*	1	0
BWTE		*	Blue-winged teal	*Anas discors*	20	27
CCSP			Clay-colored sparrow	*Spizella pallida*	35	35
CHSP	^{r}		Chipping sparrow	*Spizella passerina*	2	2
COSN		*	Common snipe	*Gallinago gallinago*	4	6
COYE		*	Common yellowthroat	*Geothlypis trichas*	4	8
GADW		*	Gadwall	*Anas strepera*	12	15
GRCA	^{r}		Gray catbird	*Dumetella carolinensis*	1	0
GWTE		*	Green-winged teal	*Anas crecca*	7	3
HOGR	^{r}	*	Horned grebe	*Podiceps auritius*	4	1
HOWR	^{r}		House wren	*Troglodytes aedon*	1	0
KILL	^{r}	*	Killdeer	*Charadrius vociferous*	1	2
LEFL	^{r}		Least flycatcher	*Empidonax minimus*	1	1
LESC	^{r}	*	Lesser scaup	*Aythya affinis*	3	1
LCSP			LeConte's sparrow	*Ammodramus leconteii*	20	28
LEYE	^{r}	*	Lesser yellowlegs	*Tringa flavipes*	0	3
MALL		*	Mallard	*Anas platyrhynchos*	16	15
MAWR	^{r}	*	Marsh wren	*Cistothorus palustris*	0	1
NOHA	^{r}	*	Northern harrier	*Circus cyaneus*	0	1
NOOR	^{r}		Northern oriole	*Icterus galbula*	1	0
NOPI	^{r}	*	Northern pintail	*Anas acuta*	1	2
NSHO		*	Northern shoveler	*Anas clypeata*	16	19
RBGU	^{r}	*	Ring-billed gull	*Larus delawarensis*	1	0
REDH	^{r}	*	Redhead	*Aythya americana*	3	1

RTHA	r		Red-tailed hawk	*Buteo jamaicensis*	2	1
RUDU		*	Ruddy duck	*Oxyura jamaicensis*	6	3
RWBL		*	Red-winged blackbird	*Agelaius phoenicus*	23	29
SASP			Savannah sparrow	*Passerculus sandwichensis*	38	54
SEWR	r	*	Sedge wren	*Cistothorus platensis*	2	1
STSP			Nelson's sharp-tailed sparrow	*Ammodramus nelsoni*	2	4
SORA		*	Sora	*Porzana carolina*	7	13
SOSP			Song sparrow	*Melospiza melodia*	14	7
TRSW		*	Tree swallow	*Tachycineta bicolor*	5	3
VESP	r		Vesper sparrow	*Pooecetes gramineus*	2	2
VIRA	r	*	Virginia rail	*Rallus limicola*	1	0
WILL	r	*	Willet	*Catoptrophorus semiplamatus*	2	2
WIPH	r	*	Wilson's phalarope	*Phalaropus tricolor*	0	3
YEWA			Yellow warbler	*Dendroica petechia*	6	6
YHBL		*	Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	8	7

Table 3.4: Results of Correspondence Analysis (CA) applied to 100 wetlands (55 restored) with 22 bird species in the PPR of Alberta and Pearson correlations (r) for 15 habitat characteristics with axes. Abbreviations for habitat characteristics can be found in Table 1. * indicates p<0.05, ** indicates p<0.10

	AX1		AX2		AX3		Total inertia
Eigenvalue	0.44		0.30		0.27		3.14
Cummulative % variance of species data	0.14		0.24		0.32		
Habitat characteristics:							
SHAPE	0.10		0.25	*	0.05		
LOGAREA	0.48	**	0.06		-0.12		
MNBASIN	-0.42	**	0.08		0.11		
LOGUPHT	0.05		-0.19	*	0.02		
SQCOND	0.36	**	0.10		-0.07		
MNDPTH	0.63	**	0.13		-0.06		
MNLOW	-0.29	**	0.04		-0.08		
MNSHAL	-0.38	**	-0.17	*	0.09		
MNWET	-0.23	*	-0.02		-0.09		
NNROAD	0.02		-0.09		0.17	*	
NNWETL	-0.05		0.11		-0.08		
LWOOD	-0.20	*	0.14		-0.10		
AWOOD	0.01		0.01		0.16		
ACROP	-0.20	*	-0.10		-0.07		
ATLWETL	0.20	**	0.13		0.01		

Table 3.5: Results of Canonical Correspondance Analysis (CCA) for bird assemblages in 102 wetlands (56 restored) near Camrose, Alberta

AXES	1	2	3	4	Total inertia
Summary statistics for first 4 axes					
Eigenvalues	0.17	0.08	0.03	0.02	3.14
Species-Environment correlations	0.71	0.59	0.45	0.38	
Cummulative % variance					
of species data	5.7	8.5	9.5	10.2	
of species-environment relation	56.1	83.1	93.7	100.0	
Sum of all unconstrained eigenvalues					2.99
Sum of all canonical eigenvalues					0.30
Summary of Monte Carlo test					All Axes
eigenvalue	0.17	0.08	0.05	0.05	0.30
F-ratio	5.63	2.83	1.77	1.59	2.63
P-value	0.0001	0.00	0.09	0.05	0.00
Correlations between habitat characteristics and first 4 axes					
Correlations					
MNDPTH	-0.77 **	-0.08	-0.04	0.28 **	
SHAPE	-0.25 **	0.76 **	0.49 **	0.42 **	
ATLWETL	-0.31 **	0.09	0.55 **	-0.69 **	
MNBASIN	0.39 **	0.61 **	-0.46 **	-0.42 **	

** correlation is significant at the 0.05 level

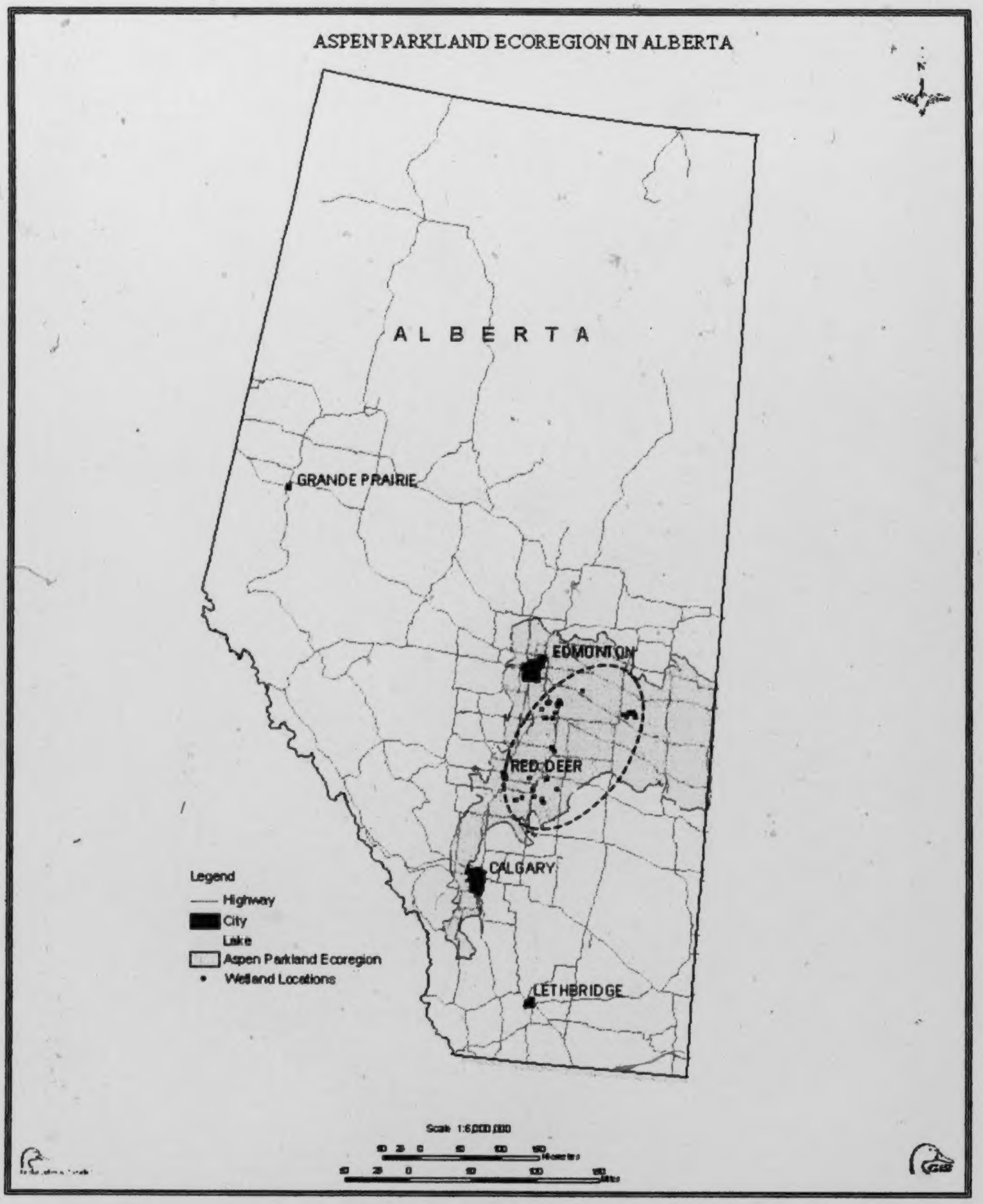
ASPEN PARKLAND ECOREGION IN ALBERTA
N
ALBERTA
GRANDE PRAIRIE
EDMONTON
RED DEER
CALGARY
LETHBRIDGE
Legend
Highway
City
Lake
Aspen Parkland Ecoregion
Wetland Locations
Scale 1:6,000,000

Figure 3.1: Location of 56 restored and 46 natural wetlands surveyed in the Aspen Parkland Ecoregion of the Prairie Pothole Region, within 100 km of Camrose, Alberta in 1999 and 2000.

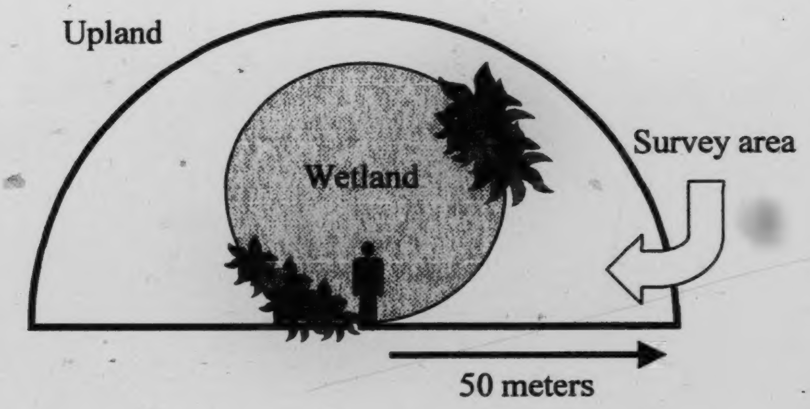
Upland
Wetland
Survey area
50 meters

Figure 3.2: Area included in avian point counts

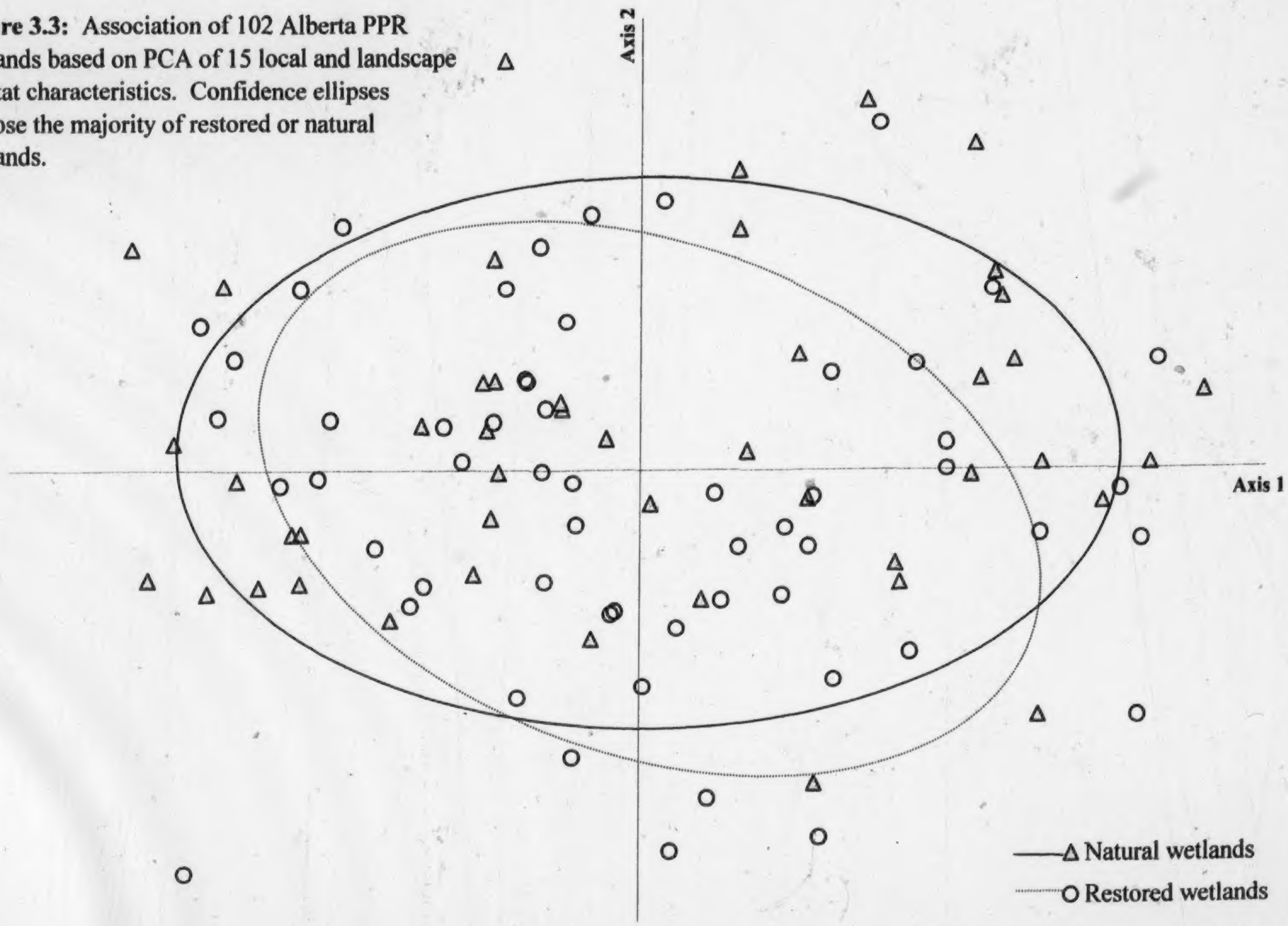

Figure 3.3: Association of 102 Alberta PPR wetlands based on PCA of 15 local and landscape habitat characteristics. Confidence ellipses enclose the majority of restored or natural wetlands.

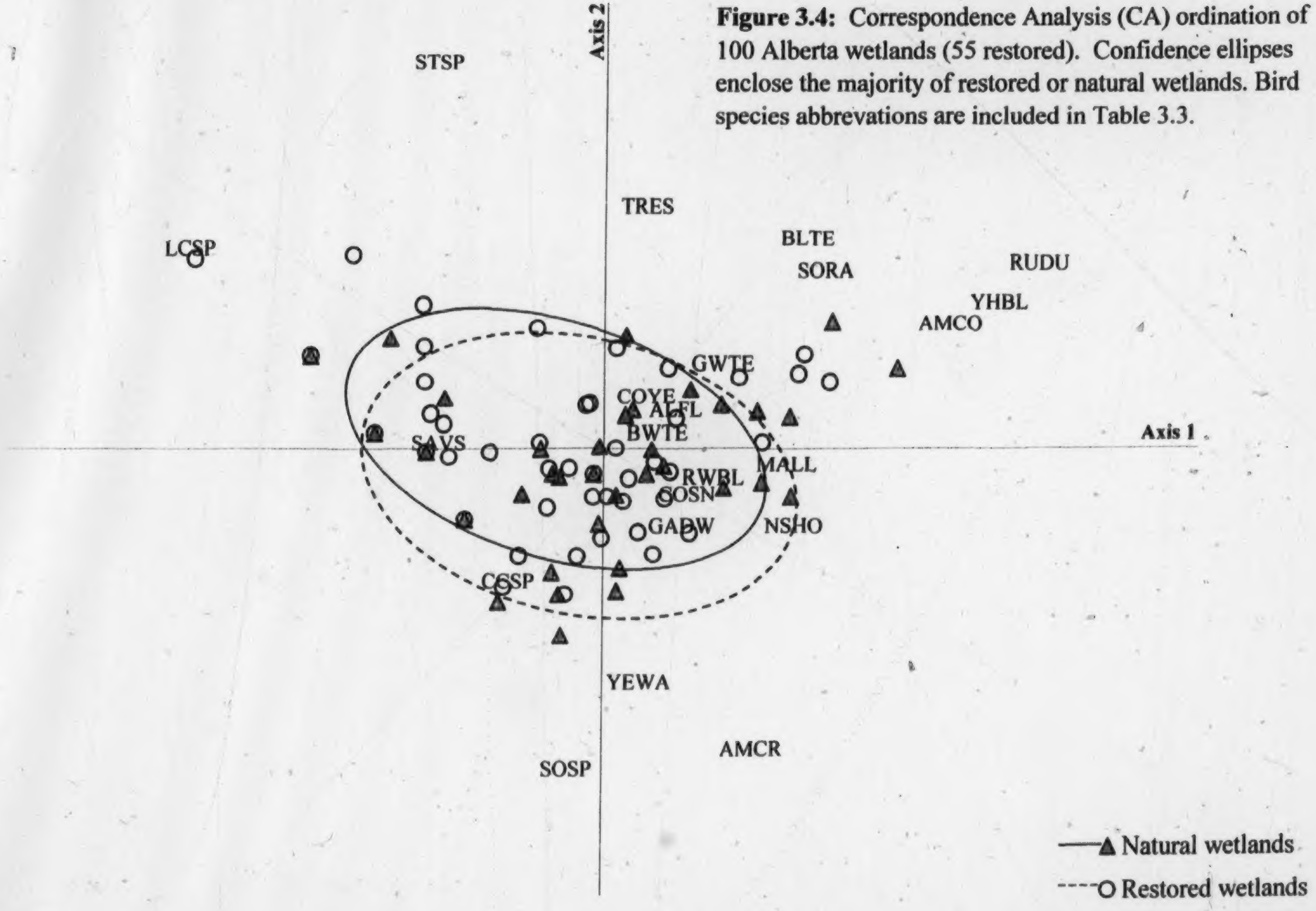

Figure 3.4: Correspondence Analysis (CA) ordination of 100 Alberta wetlands (55 restored). Confidence ellipses enclose the majority of restored or natural wetlands. Bird species abbrevations are included in Table 3.3.

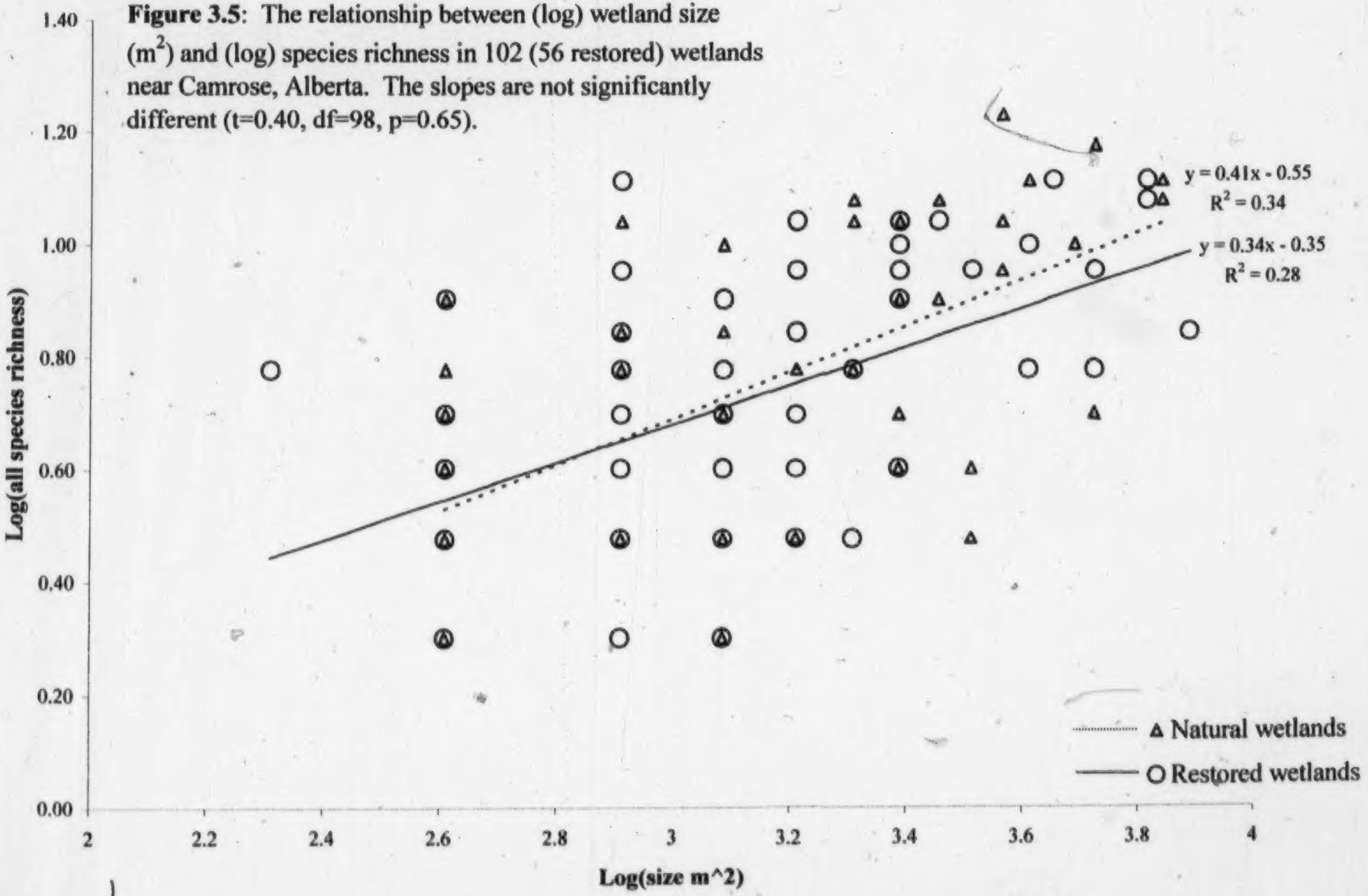

Figure 3.5: The relationship between (log) wetland size (m^2) and (log) species richness in 102 (56 restored) wetlands near Camrose, Alberta. The slopes are not significantly different (t=0.40, df=98, p=0.65).

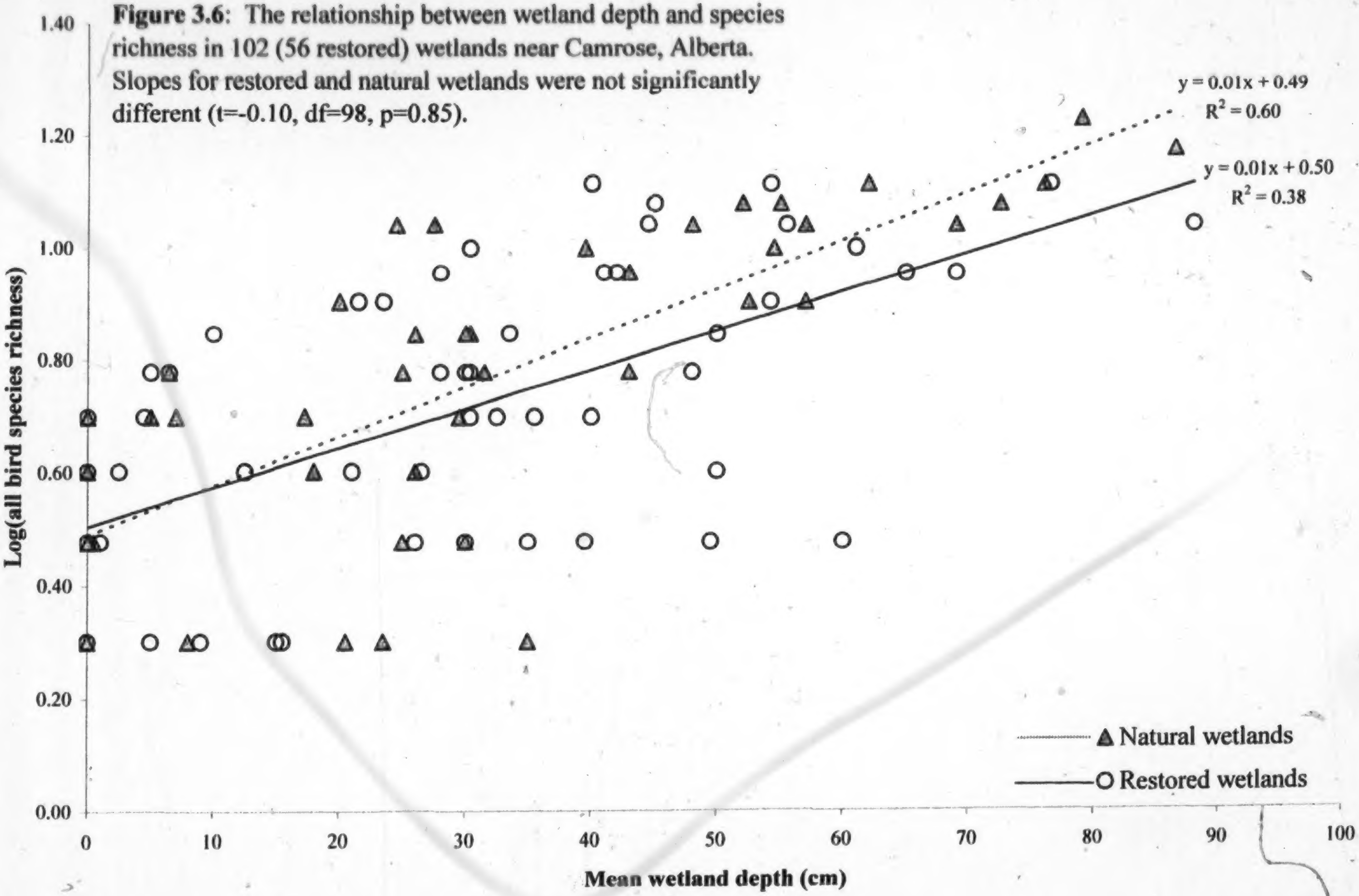

Figure 3.6: The relationship between wetland depth and species richness in 102 (56 restored) wetlands near Camrose, Alberta. Slopes for restored and natural wetlands were not significantly different (t=-0.10, df=98, p=0.85).

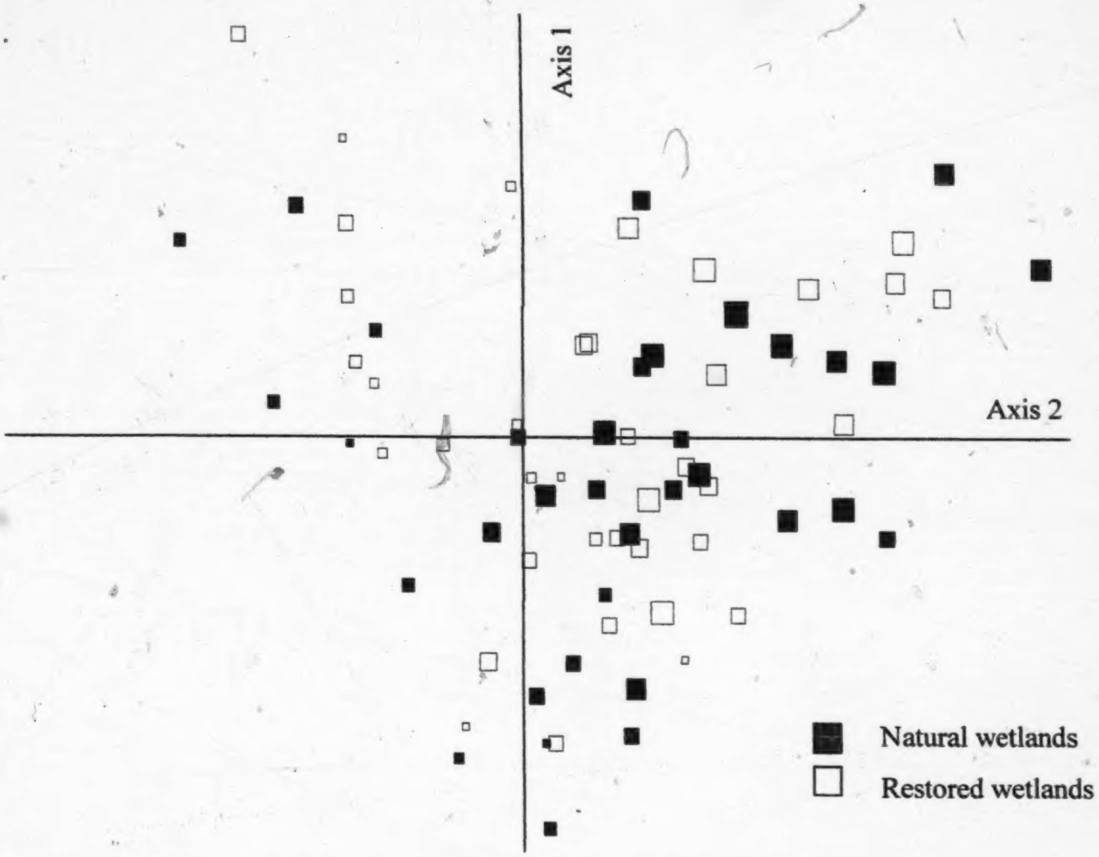

Figure 3.7: Correspondence Analysis ordination on 100 (55 restored) wetlands based on bird species assemblages (22 species). The size of each square is proportional to species richness of each wetland.

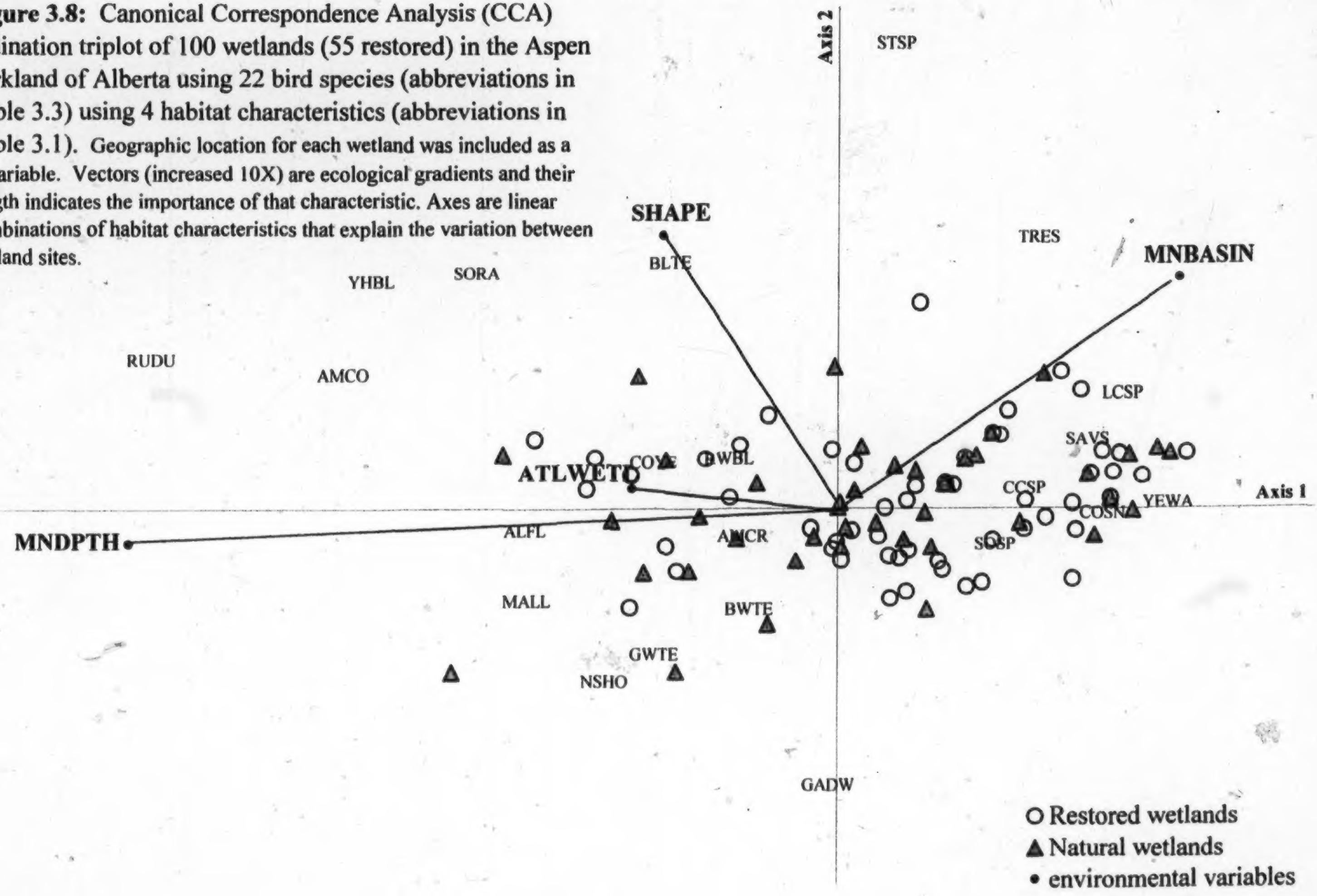

Figure 3.8: Canonical Correspondence Analysis (CCA) ordination triplot of 100 wetlands (55 restored) in the Aspen Parkland of Alberta using 22 bird species (abbreviations in Table 3.3) using 4 habitat characteristics (abbreviations in Table 3.1). Geographic location for each wetland was included as a covariable. Vectors (increased 10X) are ecological gradients and their length indicates the importance of that characteristic. Axes are linear combinations of habitat characteristics that explain the variation between wetland sites.

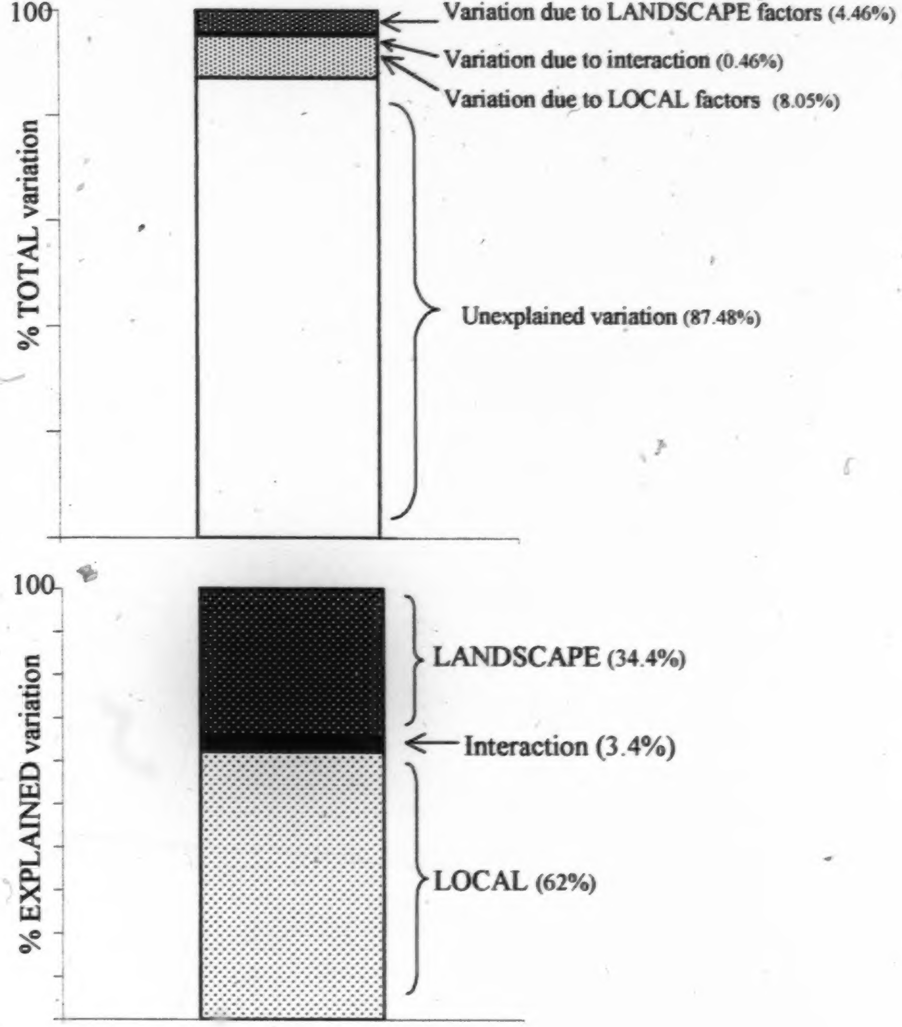

Figure 3.9: The percentage of total (above) and explained (below) variation in bird assemblage composition (22 species) that can be attributed to local and landscape habitat characteristics (and the overlap or interaction between the two groups) based on partial CCAs.

CHAPTER 4

RECOVERY OF BIRD ASSEMBLAGES IN RESTORED WETLANDS IN THE PRAIRIE POTHOLE REGION OF SASKATCHEWAN, CANADA

INTRODUCTION

Prior to European settlement, there were an estimated 8 million ha of wetlands in the Prairie Pothole Region (PPR; Leitch 1989), but drainage of these basins has been widespread and wetlands continue to be lost. The physical heterogeneity of this region, characterized by basins of different sizes, depth, and stages of plant succession, provides habitat for a variety of waterbirds with varying levels of wetland dependence and adaptation (Weller 1999). Pothole wetlands are critical habitat for waterfowl, shorebirds, passerines, and raptors providing food and cover during nesting and migration (Kantrud et al. 1989). The PPR is also the center of agricultural production for North America and agricultural development is often accompanied by wetland drainage (Lodge 1969). Throughout the PPR in Canada, wetland loss is estimated between 40% (Canada/United States Steering Committee 1986 IN Turner et al. 1987) and 70% (Anonymous 1986) and more than 90% of the remaining wetlands have been altered by agricultural expansion and urbanization (Neraasen and Nelson 1999). Degradation of wetland habitat negatively affects wildlife and has resulted in a disproportionate representation of wetland-dependent species on lists of endangered or threatened species (Gibbs 2000).

The northern one-third of the PPR, an ecotone between the true prairies of the south and the boreal forest to the north, is known as the Aspen Parkland. The Aspen Parkland is characterized by the presence of aspen (*Populus* spp.) and willow (*Salix* spp.) in the wetlands and uplands, interspersed with prairie grasslands (Walker and Coupland 1970).

In the Aspen Parkland of east-central Saskatchewan, Canada, a farming area focused on grain production and row crops, drainage has been particularly extensive (Sugden and Beyersbergen 1984; Shutler et al. 2000). In some areas (e.g. Rural Municipalities of Invermay, Buchanan, and Hazel Dell), >80% of quarter sections (64.8 ha plots) have at least one drainage ditch present and the area is considered one of the most impacted of Ducks Unlimited Canada (DUC) management areas in the Prairies (C. Deschamps, pers. commun., MFO Wadena, Saskatchewan, DUC, 2001).

As part of a mandate to enhance upland and wetland habitat for waterfowl, under the auspices of the North American Waterfowl Management Plan, DUC has restored over 900 wetlands throughout the PPR in Canada (Gray et al. 1999). The majority of wetland drainage has been accomplished using surface drains, and re-flooding can be achieved by blocking ditches (Galatowitsch and van der Valk 1994, Gray et al. 1999). (Re)creation of wildlife habitat is often the stated goal of wetland restoration, but several comparative studies in the PPR of the United States describing avian use of restored wetlands have produced equivocal results. Delphey and Dinsmore (1993) and Ratti et al. (2001) are the most comparable to the present study in objectives and techniques, but whereas Ratti et al. (2001) found similar species richness in restored and reference wetlands, Delphey and Dinsmore (1993) found wet meadow and low prairie guilds lacking in restored wetlands.

In order to ensure the success of future wetland restorations in Canada, management decisions should be directed by the successes and failures of past wetland restoration activity. By comparing the habitat and bird species assemblages in restored (cease to be artificially drained) wetlands with those of natural (relatively unaltered, reference) wetlands, I evaluated restoration in the Aspen Parkland near Foam Lake, Saskatchewan.

By characterizing habitat features and documenting avian use I attempted to address the following objectives:

1) To compare the local physical features and landscape setting of restored and natural wetlands in the Aspen Parkland of Saskatchewan.
2) To compare bird species richness and diversity in restored and natural wetlands.
3) To compare bird assemblage composition in restored and natural wetlands.
4) To investigate the relationship between local physical features and landscape setting of wetlands and the composition of bird assemblages.

Based on previous studies of restored wetlands in the PPR of the United States by Delphey and Dinsmore (1993), Galatowitsch and van der Valk (1996a,b) and VanRees-Siewert and Dinsmore (1996), I predicted the following:

1) Wet meadow and/or low prairie vegetation found in natural wetlands will be reduced or absent in restored wetlands. Unlike some wind-dispersed emergent plants, wet meadow and low prairie vegetation are dispersed by water or animals and take a greater length of time to reach restored wetland (Galatowitsch and van der Valk 1994).
2) If differences in vegetative guilds exist, bird species richness and diversity will be reduced. Several of the aforementioned studies linked depauperate plant and invertebrate communities to lower bird species richness.
3) Bird species composition will also differ between restored and natural wetlands as bird species characteristic of the wet meadow and low prairie guilds will occur less frequently or be absent from restored wetlands.

4) Bird assemblages would likely reflect the size, depth and vegetation structure of individual wetlands (Weller 1999). For example, a greater diversity of diving birds will be found in deeper wetlands and an increased diversity of passerines will be found in wetlands with greater vegetative cover. I also predicted that bird assemblages would reflect landscape setting, such as the proportion of surrounding cropland (Greenwood et al. 1995) or wetland (Brown and Dinsmore 1986, Fairbairn and Dinsmore 2001a) as these characteristics are related to the availability of an individual species' habitat and food resource needs.

To my knowledge, there have been no previous studies in Canada comparing restored and natural wetlands, and to date, no study has taken a multivariate approach to analyzing differences in species composition between restored and natural wetlands. Multivariate analyses reflect the multidimensional nature of ecological systems (McGarigal et al. 2000). A parallel study of avian use in restored and natural wetlands was conducted in the Aspen Parkland of Alberta and provided the opportunity to compare habitat remediation (i.e. wetland restoration) in areas separated by more than 800 km with different drainage histories linked to different agricultural practices. Restored wetlands in Saskatchewan displayed different patterns of bird assemblages, and the current chapter presents Saskatchewan results and provides a comparison of restoration success in both study areas.

METHODS

Study Area

Eighty wetlands (41 restored) were surveyed within 150 km of Foam Lake, Saskatchewan, Canada within the Aspen Parkland Ecoregion of the Prairie Pothole

Region. Mean July temperatures characteristic of the Aspen Parkland range from 11.7 (minimum) to 25.4 °C (maximum, taken from Saskatoon, Saskatchewan). In 2000, July temperatures ranged from 10.63 to 23.16 °C (Environment Canada climate information 2000). Overall, the climate in the Parkland is harsh with a short growing and low precipitation (mean total annual precipitation = 347 mm; Environment Canada 1996; total precipitation in Langenburg, Saskatchewan 2000 = 414 mm, Environment Canada climate information 2000).

Wetland Selection

Surveyed sites were small (<2 ha), fresh (<40-500 µS/cm) to moderately brackish (2000-5000 µS/cm), seasonal (III) or semi-permanent wetlands (IV; Stewart and Kantrud 1971) located on DUC purchased or leased property with surrounding uplands composed of planted cover or native parkland. Wetlands surveyed on the same property were >100 m apart and the average distance between wetlands was 400 m. Surveyed wetland density ranged from 1 to 5 wetlands per 64.8 ha (quarter section). Reference sites (39) were natural or relatively unaltered wetlands selected from approximately 75 wetlands of similar size and permanence located on DUC properties in the area. Restored wetlands (41) were randomly selected from more than 150 restored wetlands of similar size in the same area. Wetlands were restored using ditch plugs constructed by DUC engineering staff between 1992 and 1997. The size, age class and permanence of surveyed wetlands were representative of the company's restoration efforts. Selected restored wetlands were restored no more recently than 1997 to allow $\geq$3 years for wetlands to re-vegetate. Previous studies have shown that time is required for some plant communities to appear in newly flooded wetlands (Gray et al. 1999, Mitsch and Wilson 1996, LaGrange and

Dinsmore 1989, Sewell and Higgins 1991, Ratti et al. 2001). Specific year of restoration and location for individual restored wetlands are included in Appendix 3. The location of surveyed wetlands was referenced using GPS (Global Positioning System) in Universal Transverse Mercator (UTM) coordinates (northing, easting, zone). The study area was located on the boundary of UTM zones 13 and 14. Therefore to reduce the number of variables, UTM coordinates were converted to decimal degrees north and east for inclusion in analyses.

Habitat characteristics:

At the time of each bird survey (see below), I collected parameters to describe local wetland habitat (listed in Table 4.1). Maximum wetland depth (cm, MNDPTH) was determined by walking transects through the wetlands, and recorded using a calibrated stake. Conductivity or specific conductance (μS/cm, SQCOND) was measured using a Corning model TDS 60 portable conductivity meter *in situ* at the time of each bird survey. Conductivity is highly correlated with water salinity (Wetzel 1983) and served as an affordable proxy thereof. All wetlands were classified according to Stewart and Kantrud (1971). The proportion of the wetland with plant cover (MNBASIN) or inversely the amount of available open water habitat was recorded twice based on visual estimates. As previous studies in the southern PPR found expected vegetation zones absent or reduced and because each zone reflects vegetation of different structures, I documented the proportion of the basin covered by the following zones (as indicated by characteristic plant species) using visual estimates: low prairie (MNLOW), wet meadow (MNWET), shallow emergent marsh (MNSHAL), deep emergent marsh (MNDEEP). Following each point count, I estimated the height of surrounding upland vegetation approximately 20 m from the wetland edge in each cardinal direction (LOGUPHT). This served as a proxy for the quality of upland habitat, which is important for some upland-nesting wetland-dependant bird species (e.g. dabbling ducks, northern harrier, *Circus cyaneus*).

The landscape setting of each wetland was quantified by digitizing post-restoration air photos (1:30 000) obtained from DUC. Using Arcview 3.2 (ESRI software 1992), major habitat types were quantified in the area surrounding each surveyed wetland (the proportion within a 500 m radius). Habitat types included woodland, wetland, cropland and upland. Woodland (ARCWDL) was defined as habitat with woody species (*Populus* spp., *Salix* spp., or conifers) with a vertical height >3 m. Wetland habitat (ARCTLWET) included natural and restored basins of all sizes and classes. Cropland (ARCROP) included areas that were tilled and planted to grain or row crops, as well as fields left to fallow. Upland (ARCUPL) encompassed planted cover (a mixture of grasses planted for wildlife cover), native or naturalized grasslands, and pastures. The distance (m) to the next nearest patch of woodland (> 2ha, LOGWOOD), wetland (of any size, LOGWETL) and roadway (LOGROAD) were also recorded. Wetland area (m^2, LOGAREA) and perimeter (m, LOGPERIM) for each surveyed wetland were obtained from the digitized air photos. The extent of the basin was defined by the transition from low prairie vegetation to planted cover. Using the metrics of area and perimeter, an index of wetland shape incorporating shoreline development was calculated (McGarigal and Marks 1994).

Bird Surveys:

Wetlands were surveyed between May 21 and June 3, 2000 and a second time between June 18 and June 30, 2000. Refer to Chapter 3 (p. 63) for methods.

DATA ANALYSES

Occurrence data (presence/absence) was used in all analyses. Presence included bird species documented (observed or heard) at a wetland during the initial survey or point count and did not include "fly-overs", incidental observations or species heard during call-response survey. All bird species present were included in calculations of species richness and diversity. Bird species that were observed on <5% of all wetlands ($\leq$4, i.e. rare species) were not included in community analyses (Gauch 1982).

Habitat characteristics

Prior to analyses of the relationship of habitat characteristics and species data, I investigated potential differences in the local and landscape features between restored and natural wetlands. The distribution of individual habitat variables was examined to determine if transformation was necessary (P-P plots, SPSS 10.1.0, SPSS Inc. 1999). Normal distribution of variables can reduce the effect of outliers on results (McGarigal et al. 2000). Habitat characteristics and their respective transformations are included in Table 4.1. Individual wetland habitat characteristics were compared between restored and natural wetlands using t-tests (Zar 1999).

I calculated Pearson correlation coefficients for the transformed variables to observe potential collinearity between habitat characteristics (SPSS 10.1.0, SPSS Inc. 1999). There were strong correlations between a number of variables and MNDEEP, LOGPERIM, ARCUPL. These three variables were eliminated from further analyses.

I visually explored differences in the wetland environments further by conducting an unconstrained ordination. Detrended Correspondence Analysis (DCA) indicated that Principal Components Analysis (PCA) was appropriate (first gradient length <2.0

indicates linear data; ter Braak and Smilauer 1998). After performing PCA, I used confidence ellipses centered on means for each wetland type (Systat 9.0, SPSS Inc.1998) to assess the position of the majority of restored and natural wetlands on the resulting ordination. The major axes and orientation of these ellipses ($p=0.683$) were determined by the standard deviation and covariance for wetland types, respectively.

In order to test the similarity of habitat in restored versus natural wetlands, I compared scores from the first 3 PCA axes using Multi-Response Permutation Procedure (MRPP) with Euclidean distance measures (Zimmerman et al. 1985). MRPP is a non-parametric technique used to test the null hypothesis of no difference between *a priori* identified groups, and is analogous to discriminate analysis.

Species richness and diversity

Species richness (S), or the total number of species (including rare species) observed during timed surveys, was calculated for each wetland and compared between wetland types (restored and natural) using t-tests. Bird species diversity was calculated for each wetland using Shannon's diversity index (H) and its equitability measure (E_h), and values from restored and natural wetlands were compared statistically using t-tests.

Species composition

In order to summarize and visually assess patterns in bird species composition in restored and natural wetlands, I conducted Correspondence Analysis (CA, PCOrd 4.0, McCune and Mefford 1999). DCA indicated that CA was appropriate (first gradient length >2.0, unimodal data, ter Braak and Smilauer 1998). Confidence ellipses were used to highlight the position on the ordination of the majority of restored and natural wetlands. CA axis scores were used in MRPP (Zimmerman et al. 1985) with Euclidean distance measures to assess potential differences in species composition in restored and natural wetlands.

Initial exploration of the relationship between bird species composition and wetland environment was conducted by calculating Pearson correlation coefficients between CA axis scores and habitat characteristics (Zar 1999).

I continued to explore patterns in species composition by conducting separate CAs on wetland-dependent species (17) and upland bird species (13) alone. Wetland-dependent birds are identified in Table 4.3. All wetlands (80) were included in analyses of upland bird species. Due to the absence of wetland-dependent bird species in 5 wetlands (4 restored), analysis of wetland-dependent species was restricted to 75 wetlands (37 restored). Confidence ellipses on ordinations and MRPP analysis on CA axis scores were used to elucidate differences in composition in restored and natural wetlands for each group of species. The relationship between wetland-dependent and upland bird species and the environment were conducted by calculating Pearson correlation coefficients between CA axes scores and habitat characteristics (Zar 1999).

Species-environment relationship

I conducted Canonical Correspondence Analysis (CCA), appropriate for unimodal data, in order to evaluate directly the relationship between bird species and habitat characteristics. CCA was conducted on presence/absence data for 80 wetlands using inter-sample distance and Hill's scaling, suitable for ecological data with longer gradient lengths (McCune and Mefford 1998, ter Braak and Smilauer 1998), without downweighting of 'rare' species. Due to the size of the study area, the location of each wetland (in decimal degrees north and east) was included as a covariable in all constrained analysis. To assess the importance of each habitat characteristic, a forward selection procedure was used. The significance of habitat characteristics was tested using 1000 Monte Carlo permutations ($p<0.05$ for variable inclusion). A final ordination was conducted using significant variables and the significance of the ordination axes and overall model was tested using 9999 Monte Carlo permutations (ter Braak and Smilauer 1998).

RESULTS

Habitat characteristics

Eighty wetlands (41 restored) were surveyed for bird species and local and landscape habitat characteristics; the majority (71, 37 restored) were Class IV (semi-permanent) wetlands (Stewart and Kantrud 1971). Nine wetlands (5 restored) were Class III (seasonal) wetlands. Restored and natural wetlands were of comparable area (LOGAREA), conductivity (LOGCOND) and vegetative cover (Table 4.1, MNBASIN, MNDEEP, MNSHAL, MNWET, MNLOW). However, the overall environment of restored and natural wetlands differed significantly (MRPP, T=-3.92, p=0.005). Although there was substantial overlap between the wetland types in the PCA ordination (Figure 4.2), natural wetlands had lower scores on axis 1 and higher scores on axis 2. Scores of restored wetlands were more variable than scores of natural wetlands. Cumulatively, the first 3 PCA axes explained 38.15% of the environmental variation among wetlands (Table 4.2). Scores on the first axis were positively correlated with local vegetation patterns (MNLOW, MNWET) and negatively correlated with MNDPTH and LOGCOND (Table 4.2). Scores on the second axis were positively correlated with the proportion of the surrounding area in woodland (ARCWDL) and negatively correlated with the proportion of the surrounding area in wetland habitat (ARCTLWET) and wetland area (LOGAREA). Scores on the third axis (not shown) were also positively correlated with ARCWDL and negatively correlated with the proportion of cropland (ARCRP) and distance to nearest woodland (NNWOOD). Individual habitat characteristics indicated that natural wetlands were deeper (t=2.98, d.f. =78, p=0.004), had less complex shorelines (t=-2.15, d.f. =78, p=0.04), were closer to woodland patches (t=-3.24, d.f. =78, p=0.002) and further from roads (t=1.99, d.f. =78, p=0.05). There was a trend towards a greater proportion of woodland in the landscape (within 500 m, ARCWDL) surrounding natural wetlands (t=1.78, d.f. =78, p=0.08).

Species richness and diversity

I documented a total of 52 bird species, 29 of these are dependent on wetlands for part of their life cycle (Table 4.3, DUC, unpubl. data). No rails were recorded as a result of call response surveys. Some species were unique to either restored or natural wetland types: alder flycatcher, American crow, American redstart, barn swallow, black-capped chickadee, gray catbird and mourning dove were observed only on restored wetlands. (Scientific names are included in Table 4.3). American wigeon, canvasback, common raven, horned grebe, least sandpiper, northern flicker, pied-billed grebe, redhead, ruby-throated hummingbird, swamp sparrow and yellow-headed blackbird were observed only on natural wetlands. All of the aforementioned species were also rare species observed in <4 wetlands. In fact, aside from barn swallow (2), horned grebe (2), redhead (2) and pied-billed grebe (3), all species restricted to one wetland type were only observed at a single wetland.

The number of species per wetland (S) differed significantly between restored and natural wetlands with a mean of 9.7 (±3.0, range=5-16) for natural wetlands and 8.1 (±2.6, 3-15) for restored wetlands (95% confidence interval for the difference in means=0.39 – 2.90; t=2.61, d.f. =78, p=0.01). Species diversity (H) was also greater in natural wetlands ($H_{natural}$=2.0 ± 0.31, $H_{restored}$=1.8 ± 0.33; t=2.46, d.f. =78, p=0.02). The relative equitability across species was similar between wetland types ($E_{hnatural}$=0.91±0.04, $E_{h\ restored}$=0.90 ± 0.04; t=0.02, d.f. =78, p=0.98).

Species composition

CA of bird assemblages on 80 Saskatchewan wetlands, based on 30 species, illustrated differences in species composition in restored and natural wetlands (Figure 4.3a and b). Although there was overlap at the center of the graph, the majority of natural wetlands had negative scores on both axes, whereas the majority of restored wetlands had negative scores on axis 1 and positive scores on axis 2. Scores on the first axis were correlated with variables associated with woodland in the landscape (positively with ARCWDL, negatively with LGWOOD) and wetland area (LOGAREA, Table 4.4). Scores on the second axis were correlated positively with vegetation characteristics (MNLOW, MNWET, MNBASIN) and displayed a strong negative relationship with wetland depth (MNDPTH). Scores on the third axis were correlated with wetland depth and conductivity (LOGCOND). Assemblages on natural wetlands were characterized by the presence of woodland-associated species (American robin, brown-headed cowbird) and diving birds (ruddy duck, lesser scaup). Assemblages on restored wetlands were characterized by the presence of open grassland birds (western meadowlark, bobolink) and shorebirds (killdeer, common snipe). Compositional differences between wetland types were supported by MRPP analysis of site scores from the first 3 CA axes (T=-4.40, p=0.002).

The species ordination showed that bird species formed two clusters united by common feeding and nesting habitats (Figure 4.3a). Therefore wetlands with similar bird species composition and habitat were also clustered. Dabbling (e.g. mallard) and diving (e.g. ruddy ducks) ducks were found in deeper wetlands of moderate area with some open water areas (decreased MNBASIN). As might be expected, birds that nest in the wet meadow zones (e.g. marsh wren) were found predominantly in wetlands with greater proportions of that vegetation type. Upland passerines (e.g. American robin, song sparrow) were found in wetlands with greater surrounding woodland habitat. However, bobolink and western meadowlark were found near wetlands distant from woodlands consistent with open prairie habitats preferred by these species.

CA on 80 wetlands limited to the 13 upland bird species continued to display differences in species composition between restored and natural wetlands (Figure 4.4a and b). Scores on axis 1 were strongly correlated with surrounding woodland features (ARCWDL, NNWOOD) reflecting the difference in these features between restored and natural wetlands (Table 4.5). Woodland-nesting passerines (e.g. American robin) were characteristic of wetlands with higher scores on axis 1, and prairie (e.g. bobolink) or wetland-associated (e.g. Nelson's sharp-tailed sparrow) birds were characteristic of wetlands with lower scores on axis 1. Confidence ellipses highlighted differences in restored and natural wetlands, with a greater number of natural wetlands with high scores on axis 1. Difference in upland bird species composition between restored and natural wetlands was supported by MRPP analysis on site scores from the first 3 axes (T=-4.16, p=0.004).

I did not observe different species assemblages on restored and natural wetlands when CA was conducted for 75 wetlands (37 restored) based on only the 17 wetland-dependent species (Figure 4.5a). There was substantial overlap in the confidence ellipses for restored and natural wetlands in the CA plot (Figure 4.5b), and the similarity in species composition between wetland types was supported by MRPP analysis (T=-0.76, p=0.19). Site scores on the first two axes were weakly correlated with wetland depth (MNDPTH) and vegetation characteristics (MNSHAL, MNBASIN), and site scores on the third axis displayed a stronger correlation with MNDPTH (Table 4.6). The species ordination showed birds distributed in a pattern that weakly reflected feeding location within a wetland. Open water foragers (e.g. American coot) and dabbling ducks (e.g. blue-winged teal) were characteristic of wetlands with lower scores on the first and second axis. Birds that feed in shallow water or mudflats (e.g. killdeer) or drier wetland sites (e.g. sedge wrens) were characteristic of wetlands with higher scores on the axis 2.

Species-environment relationship

CCA results were consistent with initial species-environment patterns detected with CA. MNDPTH, NNWOOD, MNSHAL and NNROAD were included in the final CCA model and the final model and axes 1-4 were significant in explaining variation in species composition (Table 4.7). However, the final model accounted for <10% of this variation. Wetlands with higher scores on axis 1 were characterized by bird species associated with woodlands (e.g. vesper sparrow, American robin). Ubiquitous species (e.g. savannah, clay-colored and LeConte's sparrow) were clustered near the center of the plot and did not characterize any particular wetland type. Wetlands characterized by an assemblage of species with deep-water association (e.g. ruddy duck, lesser scaup) had higher scores on axis 2. Prairie upland birds (western meadowlark) characterized assemblages found on shallow wetlands with less woodland habitat and lower scores on the first and second axis.

Overall, very little of the variation in the bird species composition among wetlands was accounted by the variables measured and included in the model (<10%, MNDPTH, NNWOOD, MNSHAL, NNROAD). In addition, CA accounted for greater variation among wetlands than CCA and the CCA species-environment correlation was high, suggesting that the measured variables were important in explaining differences among sites, but that other unaccounted factors were also important (McGarigal et al. 2000). Differences among individual wetlands and the two wetland types uncovered by CCA were related to differences in local (wetland depth, proportion of shallow marsh vegetation) and landscape (distance to nearest woodland and road) features that resulted in different bird species assemblages. Deeper wetlands (MNDPTH), in closer proximity to woodlands (NNWOOD), provided habitat for a bird assemblage that included woodland associated birds and diving ducks. Shallower wetlands (MNDPTH) often had greater proportion of shallow marsh vegetation (MNSHAL) providing habitat for sedge nesting species, and were further from woodland patches (NNWOOD) providing habitat for grassland birds. Wetlands with greater distance to woodland were also further from roads (NNROAD). Restored wetlands provided adequate habitat for wetland-dependent birds, but the greater distance from woodland patches precluded the use of these sites by some species.

DISCUSSION

Although restored wetlands in the Aspen Parkland of Saskatchewan were of similar size, conductivity and vegetative cover to natural wetlands, they did not provide equivalent habitats for birds. PCA, MRPP and univariate analyses on 80 wetlands (41 restored) showed that restored wetlands were shallower, with less complex shorelines, closer to roads and further from woodland patches.

Previous studies (Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1996 a, b, VanRees-Siewert and Dinsmore 1996) have reported a reduction or absence of wet meadow and low prairie plant guilds, and contrary to my predictions, this was not the case in wetlands sampled in Saskatchewan. All vegetative zones were present in restored wetlands in proportions comparable to natural wetlands. I also documented similar plant species composition in restored and natural wetlands by intensive vegetation sampling in 7 restored and 7 natural wetlands surveyed for birds (Chapter 2).

Although I predicted, and observed, reduced bird species richness and diversity in restored wetlands, it was not related to a depauperate plant community, but rather to differences in local and landscape factors not examined by earlier studies. On average, there was a greater diversity ($H_{natural} = 2.0$, $H_{restored} = 1.8$) and number of species ($S_{natural} = 9.7$, $S_{restored} = 8.1$) in natural versus restored wetlands. Equitability or relative abundance of species was similar in both wetland types, reflecting the presence of a core group of ubiquitous species recorded on most wetlands (clay-colored sparrow, LeConte's sparrow, red-winged blackbird, savannah sparrow). Delphey and Dinsmore (1993) also found differences in species richness between natural ($S = 7.3$-8.6) and restored ($S = 3.6$-5.4) wetlands. The number of species per wetland was generally similar to values reported by other studies of restored wetlands in the PPR (mean wetland area = 1.4-3.0 ha, $S_{restored}$ = 5-9, LaGrange and Dinsmore 1989; 2.1 ha, $S_{natural}$ = 7.3-8.6, Delphey and Dinsmore 1993; 19 ha, $S_{natural}$ = 7.9, 22 ha, $S_{restored}$ = 8.4, Ratti et al. 2001) and New York (0.57 ha, $S_{natural}$=9.3, 0.85 ha, $S_{restored}$=9.2, Brown and Smith 1998). One study of larger restored wetlands (0.42-5.91 ha) reported greater species richness (S =10-13, VanRees-Siewert and Dinsmore 1996), but I observed higher species richness than similarly sized restored wetlands (2.2 ha, S = 3.5-5.4, Delphey and Dinsmore 1993; 2.6-3.0 ha, S=3.5-7.0, Hemesath and Dinsmore 1993) in other studies conducted in Iowa. Ratti et al. (2001) was the sole study to report a diversity index for restored and natural wetlands and found values that were higher than those of my study (H = 3.4 versus H = 1.8-2.0), but these North and South Dakota wetlands were also substantially larger (19-22 ha versus 0.23-0.28 ha).

Bird species that were restricted to either restored or natural wetlands were, for the most part, rare species that were observed in a single survey. Three of these species (redhead, pied-billed grebe, horned grebe) were associated with wetlands that were deeper than average (>50 cm) and had greater species richness than other surveyed wetlands (S = 10-16). These deeper basins provided the habitat required by species that feed up to 60 cm below the water's surface (i.e. diving ducks, grebes; Galatowitsch and van der Valk 1994).

Bird composition also differed between restored and natural wetlands, but not in the wet meadow and low prairie zone nesting species as predicted. CA and MRPP analyses on wetland-dependent bird species only (including wet meadow and low prairie species) indicated comparable assemblages in restored and natural wetlands. Rather, compositional differences were related to upland birds (not wetland-dependent) species such as American goldfinch, brown-headed cowbird and American robin that occurred on natural wetlands. The presence of these species was correlated with differences in the proportion of surrounding woodland and distance to nearest woodland patch in restored and natural wetlands.

During the process of wetland selection, I intentionally avoided natural wetlands with substantial woody vegetation at the wetland perimeter, as restored wetlands had been re-flooded recently without substantial time for re-growth of woody vegetation. The goal of this study was to assess the success of wetland restoration and I therefore chose to limit the influence of bird species that were not dependent on wetlands for completion of their life cycle by avoiding wetlands with conspicuous woodland perimeters. Delphey and Dinsmore (1993), for example, observed greater brown-headed cowbird parasitism of red-winged blackbirds in natural wetlands with trees present on the perimeter compared to only seedlings present in restored wetlands. By not surveying wetlands with woodland or shrubland perimeters, I aimed to reduce the occurrence of upland bird species, such as black-capped chickadees and flycatchers (*Empidonax* spp.) that would be less likely to occur along the grassy perimeter of restored wetlands. However, the distance between natural wetlands and woodlands was on average less than for restored wetlands ($\bar{x}_{natural}$=102.8 m, $\bar{x}_{restored}$=228.3 m), and facilitated the movement of upland bird species from nearby woodlands. Therefore, upland bird species with woodland associations added to or comprised a greater component of the species assemblage found on and around natural wetlands.

Wetlands that were further from woodland patches were also further from roads. While no wetland was particularly close to roads ($\bar{x}_{natural} = 450.1$ m, $\bar{x}_{restored} = 357.7$ m), restored wetlands were on average closer. Proximity to roadways may influence bird assemblage composition as species vary in their affinity for roadside habitat. Some species appear to be more abundant along roads (e.g. savannah sparrow) or trails (Baird's sparrow, *Ammodramus bairdii*; Sutter et al. 2000) and more secretive species may avoid areas with greater human activity (LeConte's sparrow, yellow rail, Ehrlich et al. 1988).

Although some compositional differences between bird assemblages on restored and natural wetlands were related to differences in landscape features, composition also reflected differences in local habitat features. In the CCA triplot, I observed how increased depth and vegetative composition of individual wetlands resulted in changes in species composition. Deeper wetlands (>50 cm) with open water areas provided foraging habitat for diving ducks (ruddy duck, lesser scaup), and shallower wetlands were characterized by species that nest or feed in shallow marsh vegetation (e.g. wrens, common yellowthroat). Although natural wetlands were on average deeper, this difference was not great enough to result in significant differences in wetland-dependent bird species composition.

Pothole wetlands are classified based on the presence of characteristic vegetation that reflects the duration of inundation (Stewart and Kantrud 1971). Increases in wetland depth (Weller 1999) and resulting changes in wetland permanence (Stewart and Kantrud 1971) can increase the diversity and availability of wetland habitat. This habitat diversity includes the wetland edge where grassland birds (e.g. savannah sparrows) and wetland-dependent passerines (e.g. common yellowthroat) feed on insects and build nests, to the cattail (*Typha* spp.) for nesting red-winged blackbirds and the deeper, open-water habitat suitable for nesting grebes and foraging diving ducks.

The shallow marsh zone, in particular, is often flooded for several weeks in the spring, but basins dry by late summer or fall in most years (Stewart and Kantrud 1971). In the wetlands of this study, a greater proportion of shallow marsh vegetation was characteristic of shallower basins with greater total vegetative basin cover. These basins provide nesting habitat for wetland obligates such as sora, marsh wren and American bittern, and greater proportions of shallow marsh vegetation reduces the available habitat for cattail or open water nesting bird species, and result in a different species composition.

The shallower depth and less complex shorelines of restored wetlands could be an artifact of the construction process, or the result of tilling and/or filling of the basin while under agricultural production. Alternately, remaining natural wetlands may not have been drained due to their size and depth and the greater difficulty in effectively draining and cultivating their shorelines. Wetland slope was not measured in this study, but wetlands that were difficult to access (with particularly steep slopes) were not included as reference wetlands.

The differences in bird assemblages that I observed between restored and natural wetlands were driven by differences in the upland bird species present and influenced by differences in the landscape setting of these two types of wetlands. These differences in the surrounding landscape were the result of previous land use on the properties surveyed. Prior to European settlement, the Aspen Parkland was a naturally patchy landscape of aspen groves, wetlands and fescue grassland (Turner et al. 1987, Walker and

Coupland 1970). In 2001, there were 26.3 million ha of land in Saskatchewan devoted to agriculture, and almost 40% of this land was seeded to row crops such as wheat, canola and barley (Statistics Canada 2001).

Attitudes, logistics, economics and modern farm equipment have made wetland drainage an integral component of agricultural practice and development (Leitch 1989, Gray et al. 1999). This has contributed to the high proportion of wetlands that have been hayed, filled, cultivated, grazed or drained. The conversion of lands to agriculture also includes clearing 'marginal lands' or woodlands (Sugden and Beyersbergen 1984, Turner et al. 1987). In fact, in an earlier study in the same area of Saskatchewan, Sugden and Beyersbergen (1984) found in more than half their study plots (112 quarter sections, 64.8 ha each), that as much as 92% (of the area in a given plot) had little or no potential for any wildlife production due to the conversion of altered uplands to annual crops, clearing of woodland and drainage of wetlands. The intensity of agriculture in the Parkland has prompted one author to call the area an endangered habitat (Rowe 1987).

Drained (and subsequently restored) wetlands were located on parcels of land that were cleared of trees for agriculture. Whereas, the remaining wetlands that ultimately served as reference wetlands in my study were found on land parcels that were either farmed less intensively, or in a few rare cases, never plowed (native grassland used as rangelands), and therefore had less woodland cleared. Landscape features such as distance to road and woodland are not local wetland features taken into account when re-flooding a drained basin, and not easily under a manager's control.

A parallel study of avian assemblages on restored wetlands was conducted in the Aspen Parkland of Alberta (Chapter 3). Generally, there were similarities in the physical features of individual wetlands, but mean bird species richness and diversity and total species composition differed. I observed a similar number of species in both provinces (Alberta 51, Table 3.3, Saskatchewan 52, Table 3.4) with substantial overlap in the overall composition. Of 63 species total, 17.5% (11 species) were unique to Alberta and 19% (12 species) were unique to Saskatchewan (Figure 4.7). The majority of species that were observed in a single province were rare species with the exception of tree swallow in Alberta, and American bittern, eastern kingbird and western meadowlark in Saskatchewan. Bobolink and sedge wren were observed in greater abundance in Saskatchewan compared to Alberta. In general, there was a trend towards increased grassland species (e.g. bobolink, western meadowlark) in Saskatchewan, and greater woodland species (e.g. alder flycatcher, tree swallow) in Alberta.

There was higher species richness and diversity in Saskatchewan (Alberta $S_{natural}$ = 6.9, $S_{restored}$ = 6.0, $H_{natural}$ = 1.54, $H_{restored}$ = 1.45; Saskatchewan $S_{natural}$ = 9.7, $S_{restored}$ = 8.1, $H_{natural}$ = 2.0, $H_{restored}$ =1.8) even though Alberta may have a larger grassland species pool (Alberta 226, Saskatchewan 211, Thayer Birding Software 1998). Wetlands of both provinces were generally of comparable area, depth, and vegetative cover, but landscape patterns differed somewhat between the provinces. Saskatchewan wetlands were set in a landscape with greater surrounding cropland and slightly less woodland.

A comparison of bird use in restored and natural wetlands in Alberta yielded comparable results to those of the present study. As in Saskatchewan, wetland-dependent bird composition was similar in restored and natural wetlands. However, restored and natural wetlands in Alberta also had equivalent physical habitats, bird species richness and diversity, and total species composition. I believe that the difference in similarity of restored and natural wetlands reflects the differences in land use in the two provinces.

The agricultural economies of the two provinces are substantially different. As discussed, Saskatchewan has historically been a grain producing, row-crop dominated farm region (4 million ha spring wheat; Statistics Canada 2001). Whereas, Alberta has less land in agriculture (21 million ha of farmland versus 26.3 million), and a much larger cattle industry with 6.6 million animals (versus 3 million in Saskatchewan; Statistics Canada 2001) with only 2 million hectares seeded to spring wheat. Lands used for pasture are less likely to be drained of wetlands or cleared of woodlands. The result is an Albertan landscape with greater perennial cover (including woodlands) and greater similarity between properties with remaining wetlands and properties with restorations (J. Thompson, Ducks Unlimited Canada, pers. commun. 2002). However, I do not know the land use history associated with each of the properties in this study, and cannot directly support these generalizations. An investigation into previous land-use is needed to determine the relationship between historical land use and the differences in the landscape setting of restored and natural wetlands. Here, it must be restated that regardless of differences in landscape composition, restored wetlands of both provinces are providing comparable habitat for wetland-dependent birds.

Further research should be directed toward an assessment of historical distributions of wetland size, class and density, using soil surveys (Galatowitsch 1993), macroinvertebrates (Euliss et al. 2001), plant seed banks (van der Valk et al. 1992), airphotos or historical data (verbal accounts and legal records). Galatowitsch (1993) reported that Class I and II wetlands (Stewart and Kantrud 1971) were under-represented compared to their pre-drainage extent. The greatest number of wetland species will benefit if the conservation and restoration of wetlands encompasses a range of classes and sizes (Naugle et al. 2001). An integrated conservation approach would identify and prioritize wetland sizes and classes that are under-represented in the current landscape and aim to reduce isolation (distance) between individual wetlands (Gibbs 2000).

Although I have documented some differences in restored and natural wetlands, wetland restoration in Canada is providing usable habitat for wetland-dependent bird species. Agricultural impacts to wetlands and surrounding uplands in Saskatchewan are not as extreme as the losses experienced in the southern PPR. In Iowa, development has resulted in losses as great as 98% and 99% of pre-settlement wetland and grasslands, respectively (Garner and Zohrer 2002). The wetland restoration studies, upon which I based my predictions, were conducted in the Iowan landscape. The degree and history of drainage in Iowa differs from that of Saskatchewan. Wetlands of the southern PPR (Iowa) have been drained longer (50 versus 10 years), more efficiently (studies report restoration of tile drained wetlands versus surface drains in Saskatchewan), and have an overall lower density of wetlands (Galatowitsch and van der Valk 1994, 1996 a, Gray et al. 1999). In Iowa, this results in drained wetlands without intact seed banks and a greater isolation of basins making seed dispersal increasingly difficult. Hydrology, and therefore re-vegetation are also affected by climatic variation (precipitation and evaporation, Hayashi et al. 1998) and there are substantial climatic differences between Saskatchewan and Iowa. Successful recovery of wildlife is critically linked to successful revegetation. I have observed comparable vegetation in restored and natural wetlands in Saskatchewan and Alberta (Chapter 2) and have subsequently documented comparable wetland-dependent bird communities. I can thus conclude that restoring Class III and IV wetlands in Saskatchewan and Alberta offers successful mitigation for wetland loss and should continue to play a regional role in habitat conservation.

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Table 4.1: Local and landscape features of 41 restored and 39 natural wetlands near Foam Lake, Saskatchewan in sampled in May - June 2000. Variables marked by ^{1} were included in PCA and CCA analyses. Variables were individually compared between restored and natural wetlands using t-tests. Significant tests are highlighted by * ($p<0.05$) or $^+$ ($p<0.10$) with a corresponding letter for test statistic below table. Variables marked with $\bar{x}$ are based on means. Landscape habitat types are defined in the text. N/a indicates that no transformation for ordination was required.

ENVIRONMENTAL VARIABLE		Abbreviation	UNIT OF MEASURE	NATURAL WETLANDS Mean	NATURAL WETLANDS Range	RESTORED WETLANDS Mean	RESTORED WETLANDS Range		Variable transformation for ordination
LOCAL:									
wetland area	^{1}	LOGAREA	m^2	2383.3	(202.5 - 8100.0)	2815.2	(405.0 - 12150.0)		$\log_{10}$
wetland perimeter		LOGPERIM	m	188.0	(56.3 - 547.2)	232.8	(72.4 - 917.3)		$\log_{10}$
shape index	^{1}	SHAPE	-	1.2	(1.0 - 1.8)	1.3	(1.0 - 2.4)	^{*a}	n/a
maximum wetland depth	$\bar{x}$ ^{1}	MNDPTH	cm	45.5	(11.0 - 90.0)	35.2	(2.0 - 71.5)	^{*b}	n/a
conductivity	$\bar{x}$ ^{1}	LOGCOND	µS/cm	893.9	(220.0 - 2300.0)	736.7	(150.0 - 2575.0)		$\log_{10}$
basin	$\bar{x}$ ^{1}	MNBASIN	%	66.4	(5.0 - 95.0)	69.4	(12.5 - 97.5)		n/a
proportion of deep marsh vegetation	$\bar{x}$	MNDEEP	%	46.6	(0 - 82.5)	45.5	(7.5 - 85.0)		n/a
vegetation	$\bar{x}$ ^{1}	MNSHAL	%	28.9	(5.0 - 77.5)	26.3	(0 - 55.0)		n/a
proportion of wet meadow vegetation	$\bar{x}$ ^{1}	MNWET	%	18.5	(5.0 - 32.5)	17.0	(2.5 - 35.0)		n/a
proportion of low prairie vegetation	$\bar{x}$ ^{1}	MNLOW	%	10.5	(2.5 - 25.0)	11.1	(0 - 35.0)		n/a
upland height	$\bar{x}$ ^{1}	LOGUPHT	cm	44.7	(17.5 - 125.0)	39.0	(10.7 - 73.8)		$\log_{10}$
LANDSCAPE:									
Proportion of habitat type within 500 m of surveyed wetland									
cropland	^{1}	ARCROP	%	26.5	(2.6 -50.6)	30.7	(3.3 - 77.2)		arcsin
wetland	^{1}	ARCTLWET	%	13.1	(0.8 - 24.1)	10.0	(3.1 - 17.8)		arcsin
upland		ARCUPL	%	49.0	(23.6 - 85.8)	47.8	(7.0 - 75.3)		arcsin
woodland	^{1}	ARCWDL	%	9.5	(1.1 - 29.1)	6.6	(0.1 - 32.9)	$^{+c}$	arcsin
Next nearest habitat patch									
woodland	^{1}	LOGWOOD	m	102.8	(13.0 - 344.0)	228.3	(0 -790.0)	^{*d}	$\log_{10}$
road	^{1}	LOGROAD	m	450.1	(57.0 - 1399.0)	357.7	(44.0 - 883.0)	^{*e}	$\log_{10}$
wetland	^{1}	LOGWETL	m	50.8	(13.9 - 163.0)	76.5	(262.5 - 16.0)		$\log_{10}$

^{*a} $t = -2.15$, $df = 78$, $p = 0.04$
^{*b} $t = 2.98$, $df = 78$, $p = 0.004$
$^{+c}$ $t = 1.78$, $df = 78$, $p = 0.08$
^{*d} $t = -3.24$, $df = 78$, $p = 0.002$
^{*e} $t = 1.99$, $df = 78$, $p = 0.05$

Table 4.2: Results of PCA for 15 habitat characteristics in 80 wetlands (41 restored) in Saskatchewan and correlations between the habitat characteristics and scores from the first 3 axes of the PCA. *indicates significance at p<0.05; ** indicates p<0.01.

	AX1		AX2		AX3	
Eigenvalue	2.23		1.84		1.65	
%variance	14.89		12.27		10.99	
Cummulative % variance	14.89		27.16		38.15	
Habitat characteristics						
MNLOW	0.78	**	0.10		0.02	
MNWET	0.58	**	-0.15		0.35	**
MNSHAL	0.43	**	0.24	*	0.15	
MNDPTH	-0.50	**	0.29	**	-0.08	
LOGCOND	-0.63	**	-0.21		-0.27	**
LOGUPHT	0.30	**	-0.03		-0.01	
MNBASIN	0.10		-0.38	**	0.34	**
ARCCRP	0.16		-0.13		-0.52	**
ARCTLWET	-0.15		-0.60	**	0.38	**
ARCWDL	-0.22	*	0.60	**	0.58	**
LOGAREA	-0.02		-0.62	**	0.22	
SHAPE	0.00		-0.37	**	0.24	*
NNWOOD	0.19		-0.42	**	-0.46	**
NNROAD	-0.28	**	-0.09		0.50	**
NNWETL	0.33	**	-0.02		-0.02	

Table 4.3: Fifty-two avian species documented in restored (41) and natural (39) wetlands in the Prairie Parkland near Foam Lake, Saskatchewan, Canada. * indicates wetland dependent species as defined by Ducks Unlimited Canada (unpubl. data). r indicates species considered rare (observed <4 wetlands total) that were not included in community analyses. Code represents abbreviation used in figures.

CODE		Common Name	Genus species	Documented presence in X number of wetlands	
				natural wetlands (39)	restored wetlands (41)
ALFL	r *	Alder flycatcher	*Empidonax alnorum*	0	1
AMBI	*	American bittern	*Botaurus lentiginosus*	1	3
AMCO	*	American coot	*Fulica americana*	14	4
AMCR	r	American crow	*Corvus brachyrhynchos*	0	1
AMGO		American goldfinch	*Carduelis tristas*	3	1
AMRE	r	American redstart	*Setophaga ruticilla*	0	1
AMRO		American robin	*Turdus migratorius*	3	2
AMWI	r *	American wigeon	*Anas americana*	1	0
BASW	r *	Barn swallow	*Hirundo rustica*	0	2
BCCH	r	Black-capped chickadee	*Poecile atricapillus*	0	1
BHCO		Brown-headed cowbird	*Molothrus ater*	4	3
BLTE	*	Black tern	*Childonias niger*	4	2
BOBO		Bobolink	*Dolichonyx oryzivorus*	21	21
BWTE	*	Blue-winged teal	*Anas discors*	24	16
CANV	r *	Canvasback	*Aythya valisineria*	1	0
CCSP		Clay-colored sparrow	*Spizella pallida*	39	40
CORA	r	Common raven	*Corvus corvax*	1	0
COSN	*	Common snipe	*Gallinago gallinago*	5	3
COYE	*	Common yellowthroat	*Geothlypis trichas*	9	12
EAKI		Eastern kingbird	*Tyrannus tyrannus*	7	1
GADW	*	Gadwall	*Anas strepera*	14	10
GRCA	r	Gray catbird	*Dumetella carolinensis*	0	1
GWTE	*	Green-winged teal	*Anas crecca*	6	1
HOGR	r *	Horned grebe	*Podiceps auritius*	2	0
KILL	*	Killdeer	*Charadrius vociferous*	2	3
LEFL	r	Least flycatcher	*Empidonax minimus*	2	1
LESA	r *	Least sandpiper	*Calidris minutilla*	1	0
LESC	*	Lesser scaup	*Aythya affinis*	10	4
LESP		Leconte's sparrow	*Ammodramus leconteii*	27	29
MALL	*	Mallard	*Anas platyrhynchos*	15	14
MAWR	*	Marsh wren	*Cistothorus palustris*	3	4
MODO	r	Mourning dove	*Zenaida macroura*	0	1
NOFL	r	Northern flicker	*Colaptes auratus*	1	0
NOHA	r *	Northern harrier	*Circus cyaneus*	1	2
NSHO	*	Northern shoveler	*Anas clypeata*	11	12
PBGR	r *	Pied-billed grebe	*Podilymbus podiceps*	3	0
REDH	r *	Redhead	*Aythya americana*	2	0

RTHA	r		Red-tailed hawk	*Buteo jamaicensis*	1	2
RTHU	r		Ruby-throated hummingbird	*Archilochus colubris*	1	0
RUDU		*	Ruddy duck	*Oxyura jamaicensis*	4	1
RWBL		*	Red-winged blackbird	*Agelaius phoenicus*	32	33
SASP			Savannah sparrow	*Passerculus sandwichensis*	32	40
SEWR		*	Sedge wren	*Cistothorus platensis*	14	12
SORA		*	Sora	*Porzana carolina*	13	9
SOSP			Song sparrow	*Melospiza melodia*	17	8
STSP			Nelson's sharp-tailed sparrow	*Ammodramus nelsoni*	4	12
SWSP	r	*	Swamp sparrow	*Melospiza georgiana*	1	0
VESP			Vesper sparrow	*Pooecetes gramineus*	5	3
WEME			Western meadowlark	*Sturnella neglecta*	1	4
WIPH	r	*	Wilson's phalarope	*Phalaropus tricolor*	2	1
YEWA			Yellow warbler	*Dendroica petechia*	15	11
YHBL	r	*	Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	1	0

Table 4.4: Results of Correspondence Analysis (CA) applied to 80 wetlands (41 restored) with 30 bird species in the PPR of Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. Abbreviations for habitat characteristics can be found in Table 4.1.
* indicates significance at $p<0.05$; ** indicates $p<0.01$.

	AX1		AX2		AX3		Total inertia
Eigenvalue	0.2528		0.216		0.1787		2.4028
Cummulative % variance of species data	0.11		0.20		0.27		
Habitat characteristics:							
MNLOW	-0.06		0.27	**	-0.08		
MNWET	0.09		0.33	**	-0.01		
MNSHAL	0.10		0.10		-0.28	**	
MNDPTH	0.01		-0.42	**	0.31	**	
LOGCOND	-0.16		-0.13		0.31	**	
LOGUPHT	-0.10		-0.11		0.01		
MNBASIN	0.08		0.25	*	-0.19		
ARCCRP	-0.16		0.07		0.03		
ARCTLWET	-0.15		0.18		-0.01		
ARCWDL	0.34	**	-0.21		-0.25	*	
LOGAREA	-0.25	*	0.20		-0.14		
SHAPE	0.08		0.07		-0.04		
LGWOOD	-0.46	**	0.01		0.08		
LGROAD	-0.21		-0.04		-0.01		
LGNNWT	-0.14		0.22	*	-0.12		

Table 4.5: Results of Correspondence Analysis (CA) applied to 80 wetlands (41 restored) with 13 upland (not wetland-dependent) bird species in the PPR of Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. Abbreviations for habitat characteristics can be found in Table 1. *indicates significance at $p<0.05$; ** indicates $p<0.01$.

	AX1		AX2		AX3		Total inertia
Eigenvalue	0.333		0.258		0.226		1.742
Cummulative % variance of species data	0.19		0.34		0.47		
Habitat characteristics:							
MNLOW	-0.13		0.12		0.03		
MNWET	0.08		0.20		0.13		
MNSHAL	0.06		-0.09		-0.02		
MNDPTH	0.17		-0.05		-0.04		
LOGCOND	-0.04		0.11		0.04		
LOGUPHT	-0.01		-0.03		-0.29	**	
MNBASIN	0.01		0.08		0.17		
ARCCRP	-0.06		0.13		0.04		
ARCTLWET	-0.27	*	0.09		0.08		
ARCWDL	0.41	**	-0.23	*	0.02		
LOGAREA	-0.25	*	0.17		0.04		
SHAPE	0.09		0.07		-0.01		
LGWOOD	-0.44	**	0.01		0.04		
LGROAD	-0.10		-0.01		0.11		
LGNNWT	-0.09		0.10		0.23	*	

Table 4.6: Results of Correspondence Analysis (CA) applied to 75 wetlands (37 restored) with 17 wetland-dependent bird species in the PPR of Saskatchewan and Pearson correlations (r) for 15 habitat characteristics with axes. Abbreviations for habitat characteristics can be found in Table 1. *indicates significance at p<0.05; ** indicates p<0.01.

	AX1		AX2		AX3		Total inertia
Eigenvalue	0.303		0.269		0.261		2.550
Cummulative % variance of species data	0.12		0.22		0.33		
Habitat characteristics:							
MNLOW	-0.07		0.20		0.02		
MNWET	0.11		0.09		0.18		
MNSHAL	0.23	*	0.23	*	-0.07		
MNDPTH	-0.25	*	-0.23	*	-0.34	**	
LOGCOND	-0.11		0.15		-0.16		
LOGUPHT	0.08		-0.07		-0.08		
MNBASIN	0.27	*	0.06		0.31	**	
ARCCRP	0.04		0.13		0.04		
ARCTLWET	-0.05		0.03		0.23	*	
ARCWDL	0.10		-0.15		-0.11		
LOGAREA	0.05		0.20		0.08		
SHAPE	0.00		0.04		0.12		
LGWOOD	-0.05		0.14		-0.06		
LGROAD	-0.15		0.10		0.01		
LGNNWT	-0.08		-0.12		0.20		

Table 4.7: Results of Canonical Correspondance Analysis (CCA) for bird assemblages in 80 wetlands (41 restored) near Foam Lake, Saskatchewan, Canada. ** correlation is significant at the 0.01 level; * correlation is significant at the 0.05 level

AXES	1	2	3	4	Total inertia
Eigenvalues	0.09	0.09	0.04	0.03	2.40
Species-Environment correlations	0.67	0.73	0.71	0.54	
Cummulative % variance					
of species data	3.9	7.7	9.6	10.9	
of species-environment relation	35.7	70.3	87.7	100.0	
Sum of all unconstrained eigenvalues					2.26
Sum of all canonical eigenvalues					0.25
Summary of Monte Carlo test					All axes
eigenvalue	0.09	0.09	0.06	0.05	0.25
F-ratio	2.96	3.06	2.14	1.86	2.24
P-value	0.0020	0.0001	0.0071	0.0064	0.0001
Correlations					
MNDPTH	0.18	0.61 **	-0.31 **	0.32	
NNWOOD	-0.59 **	0.02	-0.25 *	0.15	
MNSHAL	0.00	-0.29 **	-0.51 **	-0.26 *	
NNROAD	-0.24 *	0.18	0.27 *	-0.41 **	

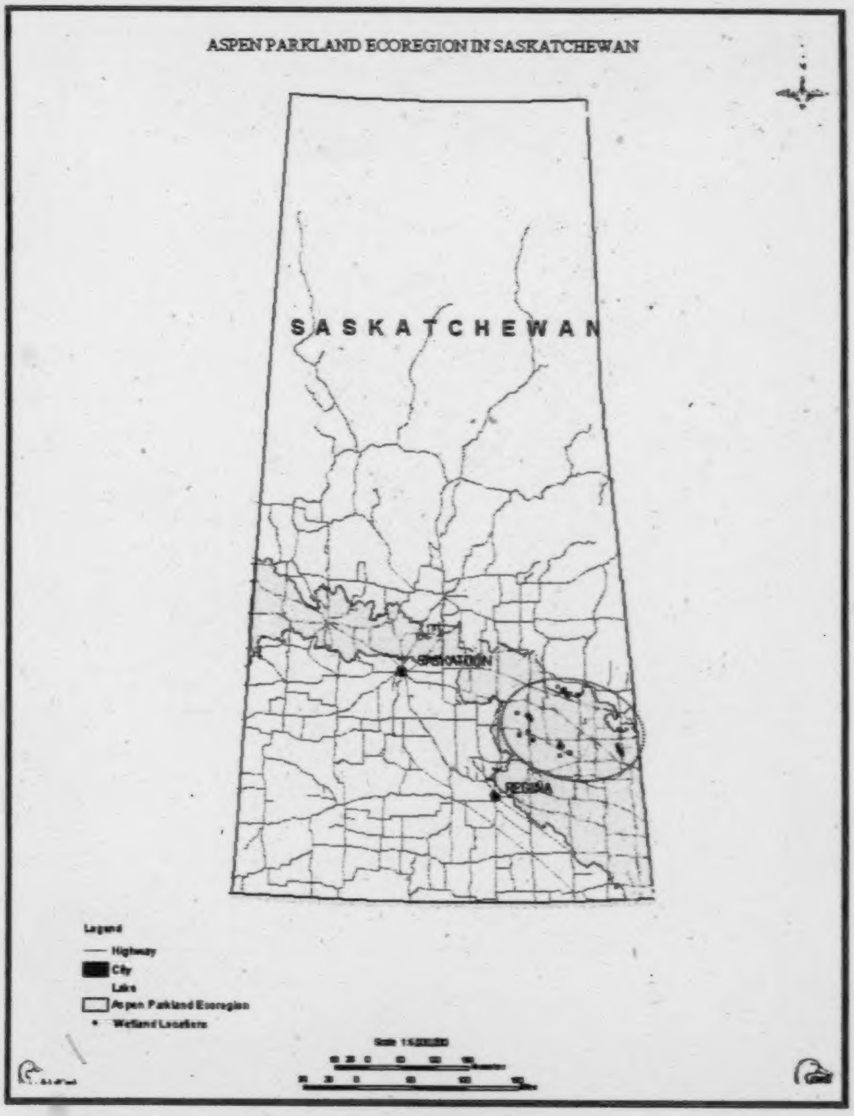
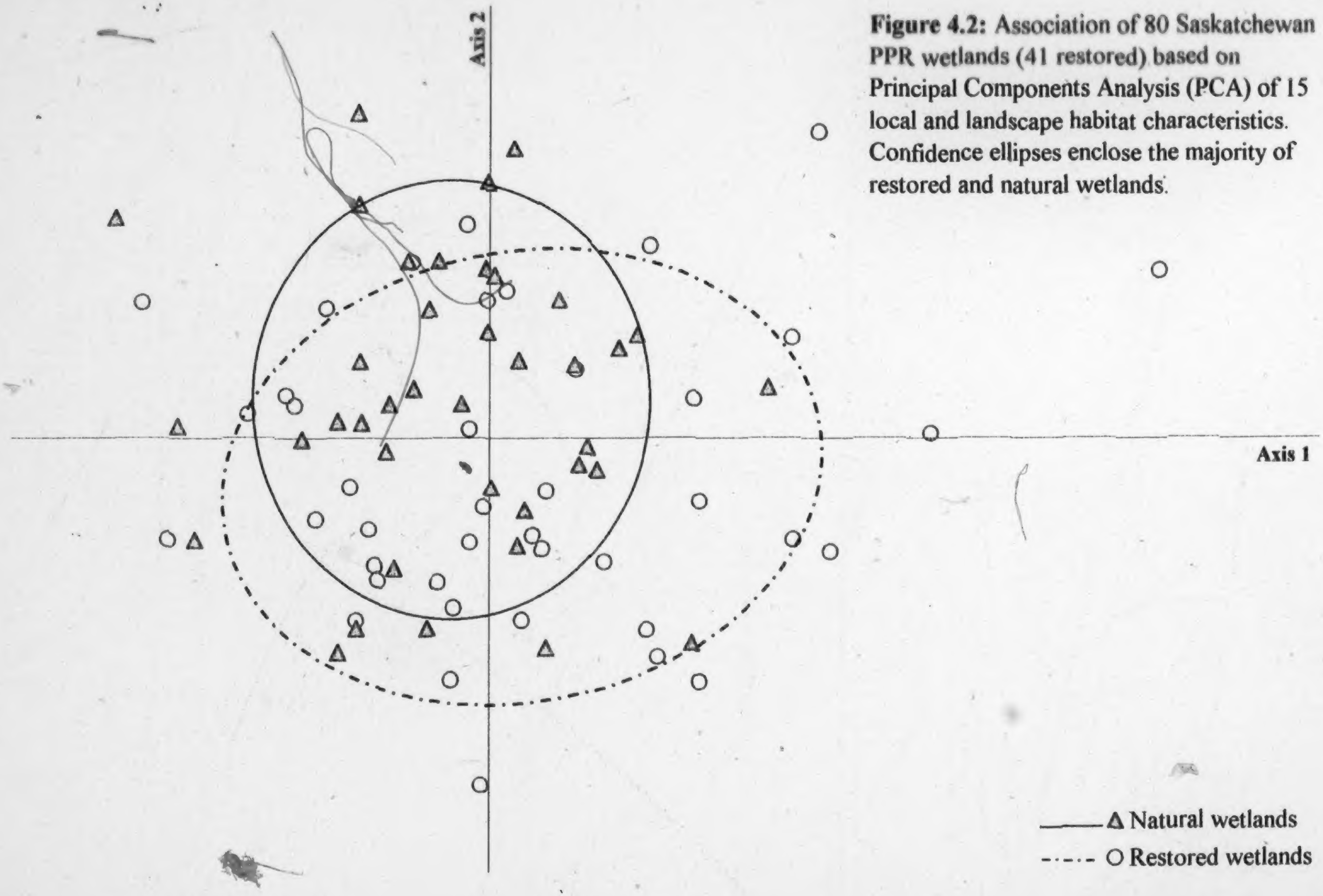

ASPEN PARKLAND ECOREGION IN SASKATCHEWAN
SASKATCHEWAN
SASKATOON
REGINA
Legend
Highway
City
Lake
Aspen Parkland Ecoregion
Wetland Locations

Figure 4.1: Location of 41 restored and 39 natural wetlands surveyed in the Aspen Parkland Ecoregion of the Prairie Pothole Region, within 150 km of Foam Lake, Saskatchewan, Canada in 2000.

Figure 4.2: Association of 80 Saskatchewan PPR wetlands (41 restored) based on Principal Components Analysis (PCA) of 15 local and landscape habitat characteristics. Confidence ellipses enclose the majority of restored and natural wetlands.



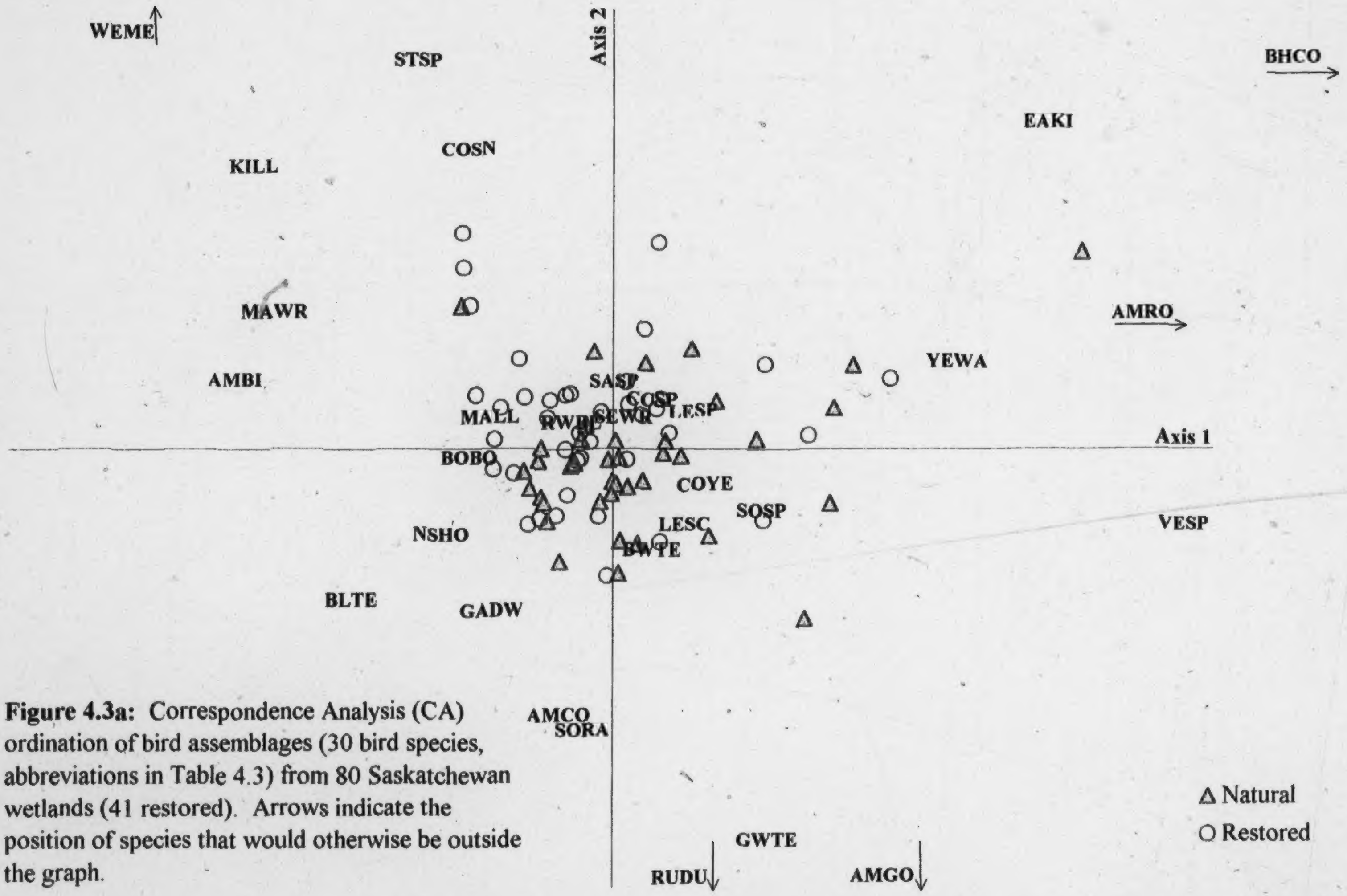


Figure 4.3a: Correspondence Analysis (CA) ordination of bird assemblages (30 bird species, abbreviations in Table 4.3) from 80 Saskatchewan wetlands (41 restored). Arrows indicate the position of species that would otherwise be outside the graph.

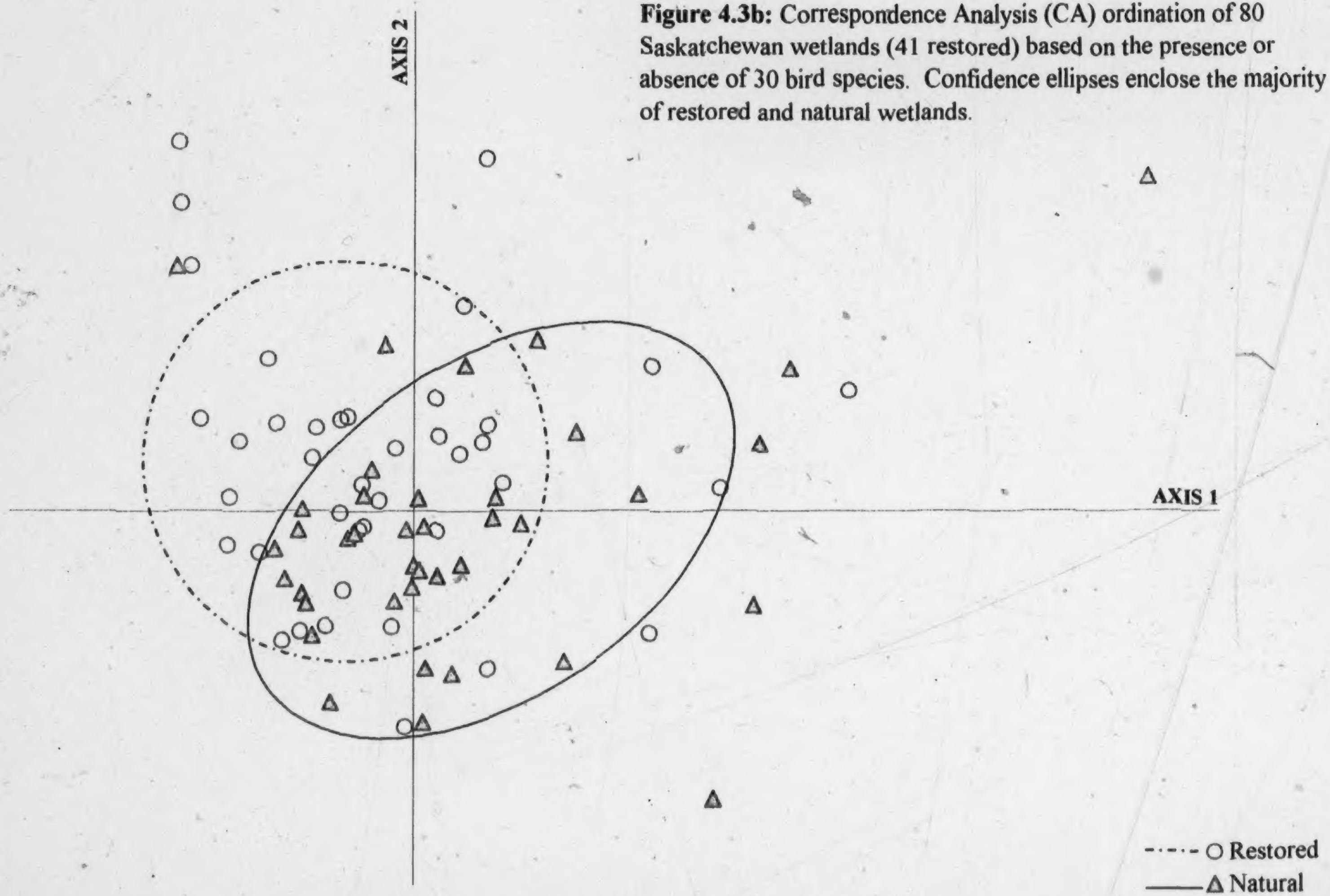


Figure 4.3b: Correspondence Analysis (CA) ordination of 80 Saskatchewan wetlands (41 restored) based on the presence or absence of 30 bird species. Confidence ellipses enclose the majority of restored and natural wetlands.

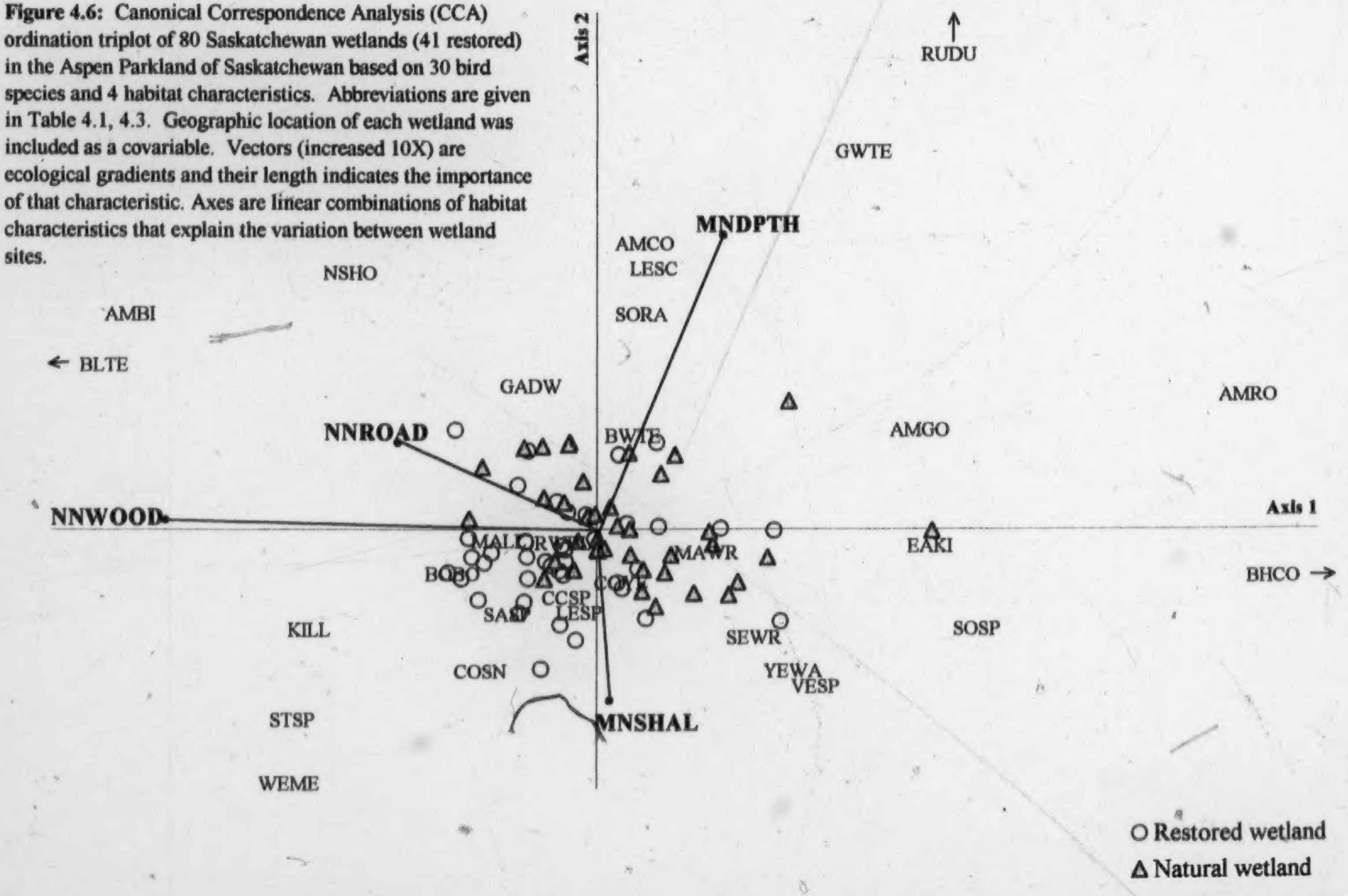
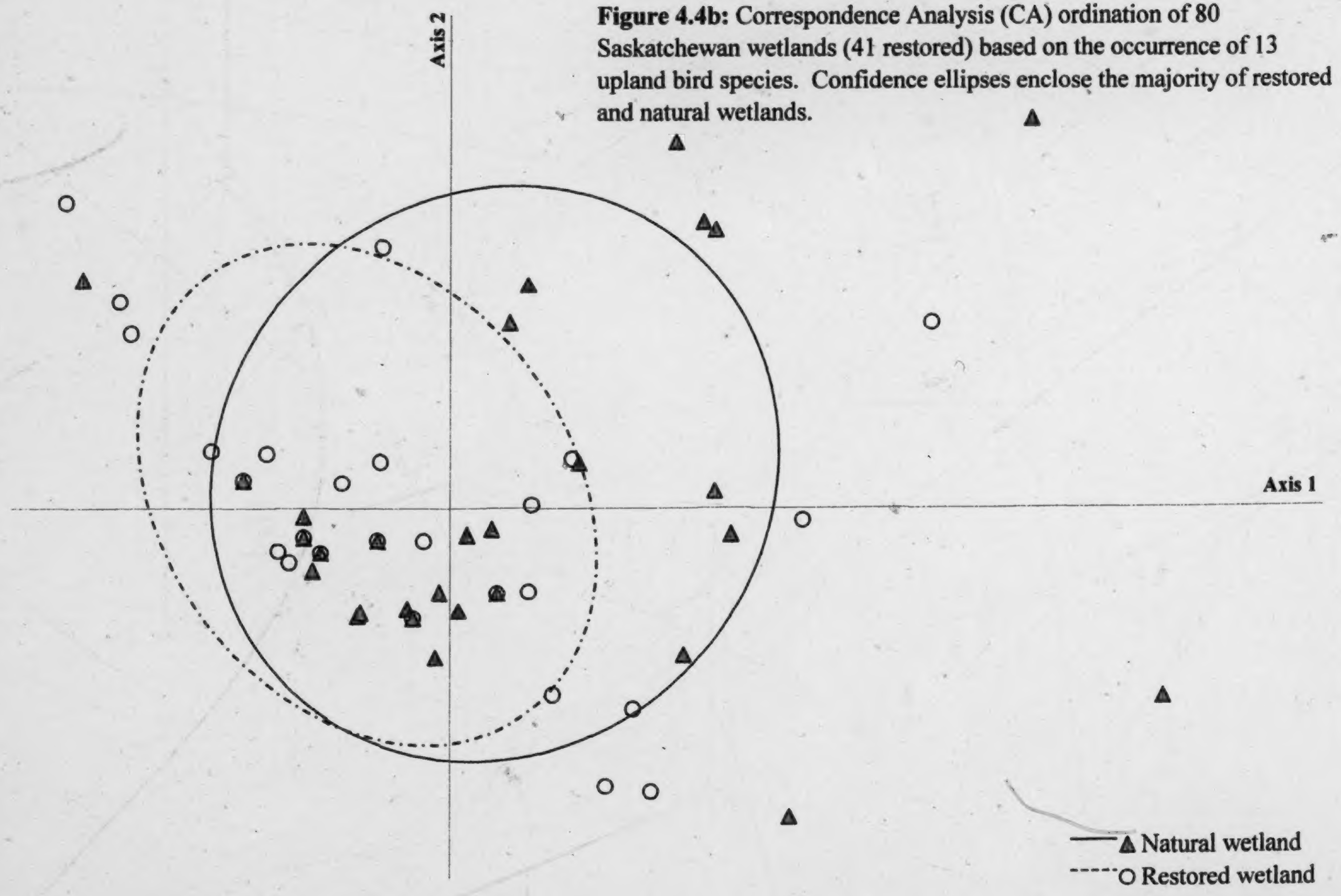


Figure 4.6: Canonical Correspondence Analysis (CCA) ordination triplot of 80 Saskatchewan wetlands (41 restored) in the Aspen Parkland of Saskatchewan based on 30 bird species and 4 habitat characteristics. Abbreviations are given in Table 4.1, 4.3. Geographic location of each wetland was included as a covariable. Vectors (increased 10X) are ecological gradients and their length indicates the importance of that characteristic. Axes are linear combinations of habitat characteristics that explain the variation between wetland sites.

Figure 4.4b: Correspondence Analysis (CA) ordination of 80 Saskatchewan wetlands (41 restored) based on the occurrence of 13 upland bird species. Confidence ellipses enclose the majority of restored and natural wetlands.



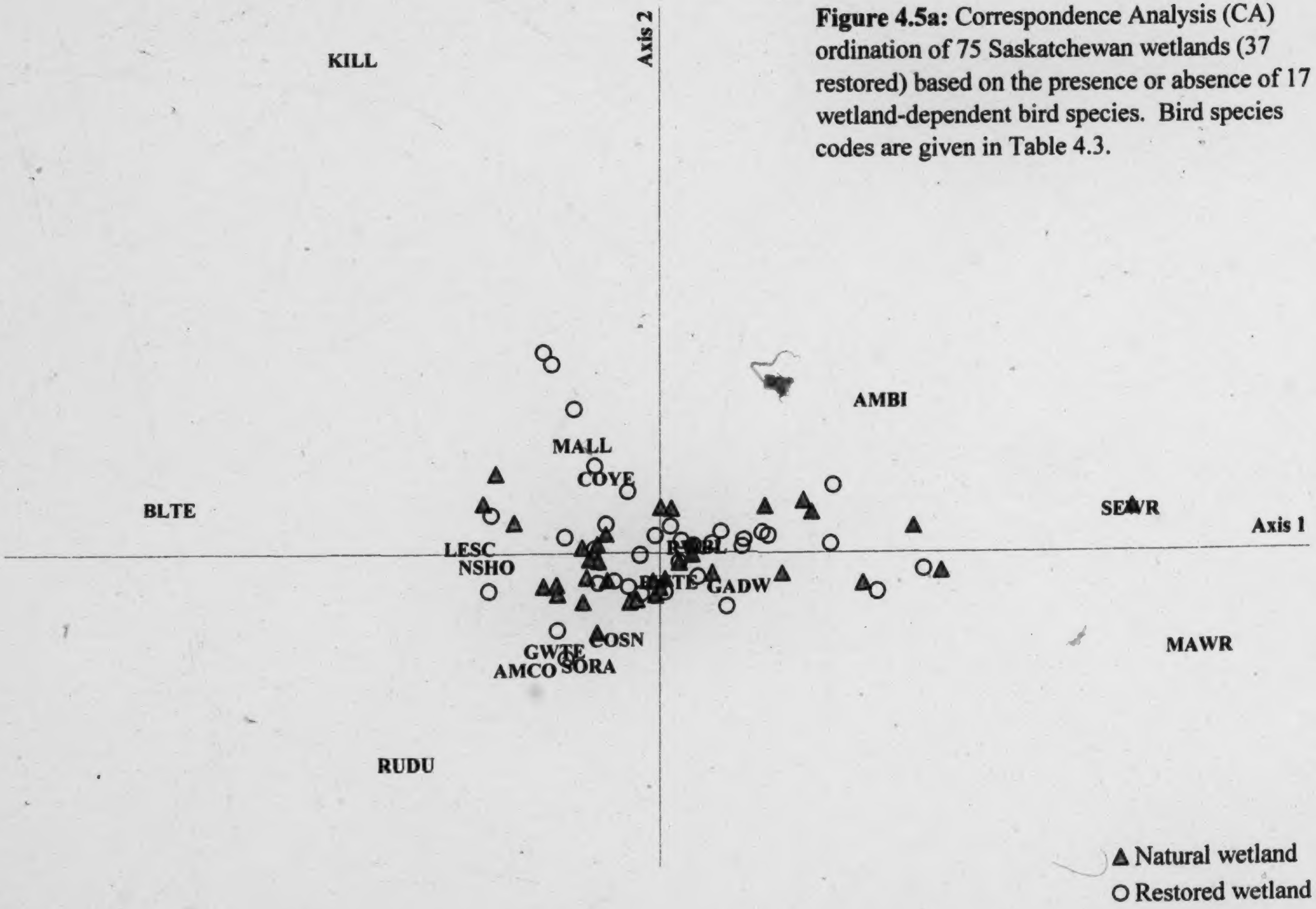


Figure 4.5a: Correspondence Analysis (CA) ordination of 75 Saskatchewan wetlands (37 restored) based on the presence or absence of 17 wetland-dependent bird species. Bird species codes are given in Table 4.3.

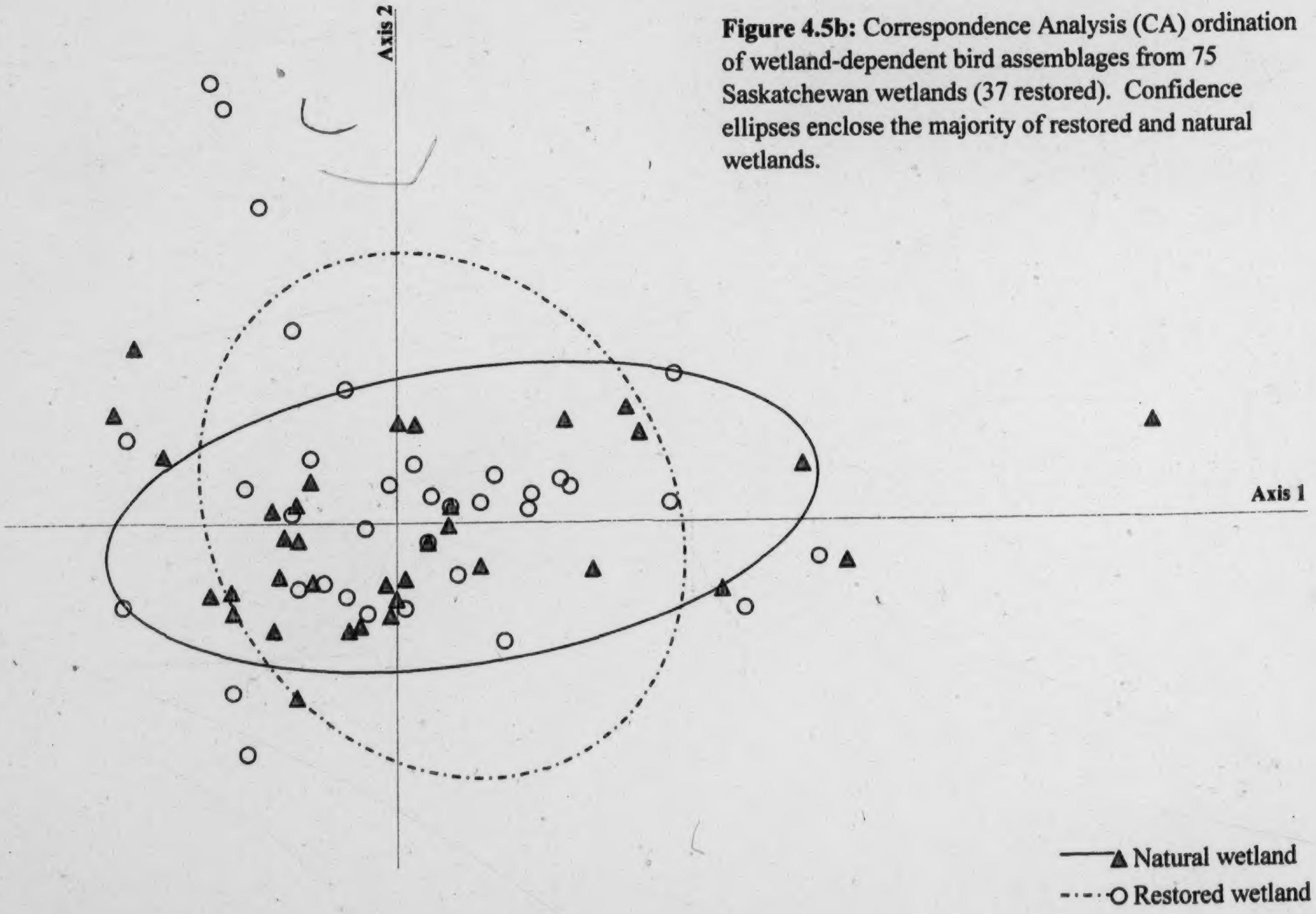


Figure 4.5b: Correspondence Analysis (CA) ordination of wetland-dependent bird assemblages from 75 Saskatchewan wetlands (37 restored). Confidence ellipses enclose the majority of restored and natural wetlands.

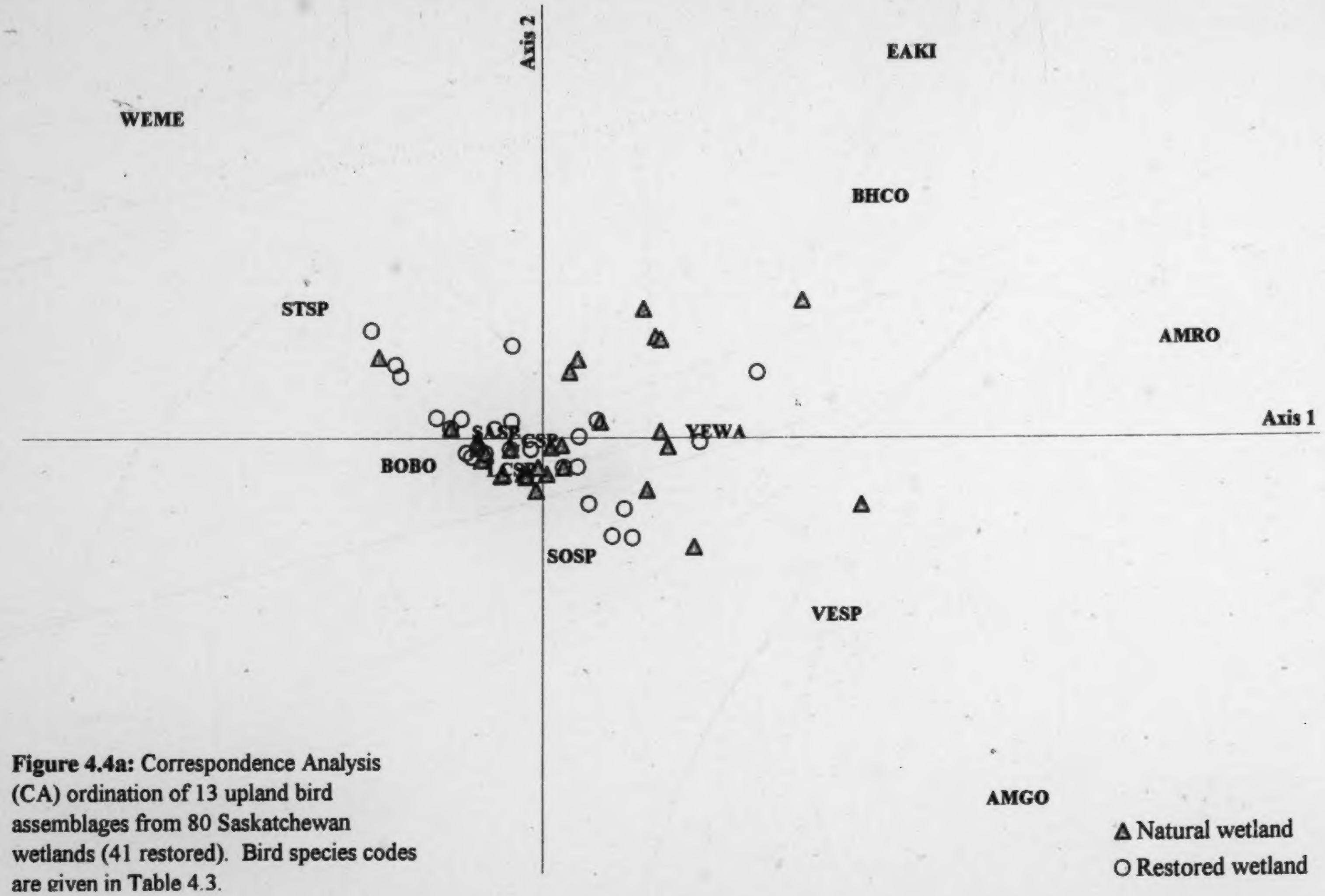


Figure 4.4a: Correspondence Analysis (CA) ordination of 13 upland bird assemblages from 80 Saskatchewan wetlands (41 restored). Bird species codes are given in Table 4.3.

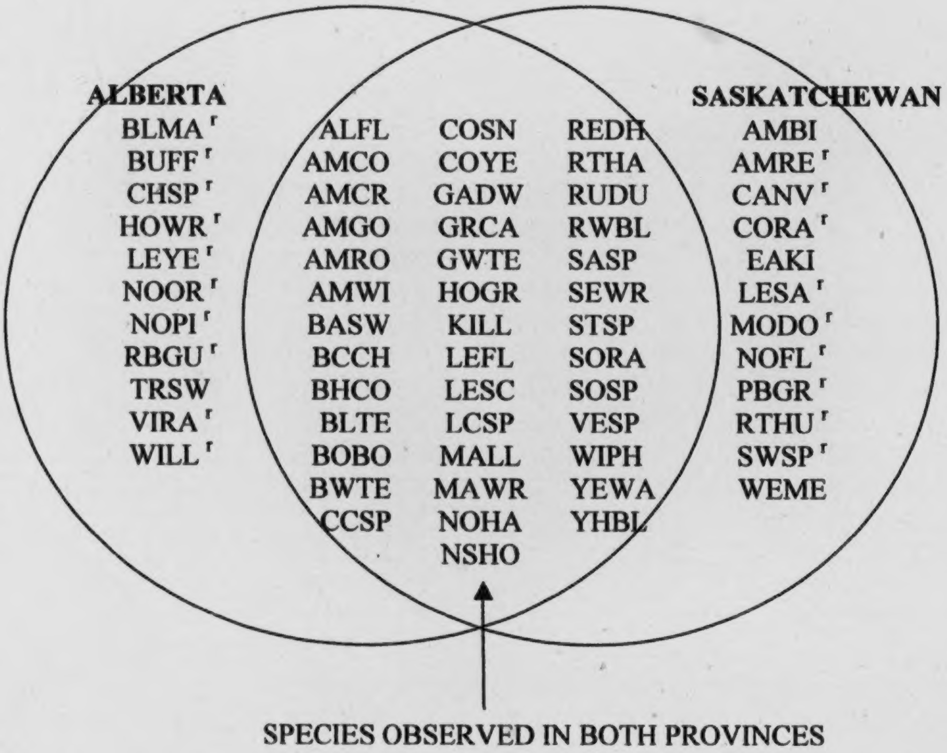

ALBERTA
BLMA ^{r}
BUFF ^{r}
CHSP ^{r}
HOWR ^{r}
LEYE ^{r}
NOOR ^{r}
NOPI ^{r}
RBGU ^{r}
TRSW
VIRA ^{r}
WILL ^{r}
ALFL
AMCO
AMCR
AMGO
AMRO
AMWI
BASW
BCCH
BHCO
BLTE
BOBO
BWTE
CCSP
COSN
COYE
GADW
GRCA
GWTE
HOGR
KILL
LEFL
LESC
LCSP
MALL
MAWR
NOHA
NSHO
REDH
RTHA
RUDU
RWBL
SASP
SEWR
STSP
SORA
SOSP
VESP
WIPH
YEWA
YHBL
SASKATCHEWAN
AMBI
AMRE ^{r}
CANV ^{r}
CORA ^{r}
EAKI
LESA ^{r}
MODO ^{r}
NOFL ^{r}
PBGR ^{r}
RTHU ^{r}
SWSP ^{r}
WEME
SPECIES OBSERVED IN BOTH PROVINCES

Figure 4.7: Venn diagram comparing avian assemblages in restored and natural wetlands between Camrose, Alberta (1999 and 2000), and Foam Lake, Saskatchewan (2000). A total of 63 species were observed. Abbreviations found in Table 3.3 and 4.3. r = rare species observed in <5% of wetlands surveyed.

CHAPTER 5

A COMPARISON OF AMPHIBIAN ASSEMBLAGES IN RESTORED AND NATURAL WETLANDS IN PRAIRIE CANADA

INTRODUCTION

Amphibians depend on discrete wetland and terrestrial habitats through the course of the year for breeding, summer foraging and hibernation (Heyer et al. 1994, Semlitsch 1998, Seburn and Seburn 2000). This dual life cycle (aquatic larvae, terrestrial adults) makes them dependent on wetlands for breeding and their permeable skin limits the range of terrestrial habitats available year round (Reaser 2000). Amphibians are important components of biodiversity and serve as trophic links in terrestrial and aquatic ecosystems. Larvae graze on algae, adults prey on small invertebrates, and amphibians are prey for mammals, birds, fishes, reptiles, invertebrates and other amphibians. As well, amphibians can act as indicators of environmental change (Reaser 2000).

Declines in amphibian populations have been widely documented and habitat loss and degradation have been accepted as one of the major causes (Semlitsch 2002). Loss of wetlands in the Canadian Prairie Pothole Region (PPR) is approximately 40% (Canada/United States Steering Committee 1986 IN Turner et al. 1987), but exceeds 70% in urban areas (Anonymous 1986) with >90% of the remaining basins negatively impacted by urbanization and agricultural expansion (Neraasen and Nelson 1999). It is not unexpected, that a disproportionate number of animals on endangered species lists in the U.S., such as amphibians, are wetland-dependent (Gibbs 2000).

It has been proposed that amphibian assemblages are structured as metapopulations, that is a network of multiple local populations that are connected by migration, extinction and colonization (Hanski and Gilpin 1991). Local populations are often small and isolated and therefore vulnerable to extinction (Gibbs 1993). These dynamics are controlled by the number of individuals moving between wetland habitats and by the diversity and distribution of wetlands within a landscape (Semlitsch 2000, 2002).

The physical and chemical characteristics of a wetland determine if a particular species of amphibian can use it for reproduction and foraging. Changes in area and depth often result in changes to wetland permanence (Stewart and Kantrud 1971, Kantrud and Stewart 1984). The duration of ponding in a wetland incurs opposing selection pressures on amphibians; hydroperiod must be long enough to allow larval development and metamorphosis, but the most permanent wetlands have the greatest number of predators (fishes, salamanders, diving beetles, or dragonfly larvae; Skelly 1997). Emergent and submergent vegetation provide important sites for oviposition (Takats 1997, Preston 1982), refuge from predators and sites for foraging or calling in the spring (Semlitsch 2002, Stratman 2000 IN Semlitsch 2002, Galatowitsch and van der Valk 1994).

Water chemistry can also influence the presence and species richness of amphibians at a given wetland. Increased acidity or heavy metal concentration can result in larval mortality and toxic conditions for adults (Hecnar and M'Closkey 1996, Glooschenko et al. 1992). Nitrogen and phosphorus loading from agricultural inputs (Neely and Baker 1989) can influence algal production (Crumpton 1989) with important consequences for larval feeding and development. High nitrate concentrations (2.5-100 mg/L) may not only affect food resources, but can cause death and developmental abnormalities in amphibians (Rouse et al. 1999).

Aside from northern leopard frogs (*Rana pipiens*), amphibians in the northern PPR over-winter in terrestrial habitats under litter or in burrows (Conant and Collins 1991), and forage in upland forests in the summertime (Zug 1993). Access to wetland and appropriate upland or woodland habitats are therefore critical to survival and metapopulation maintenance. The ability to travel between critical habitats can be hindered by potential barriers, such as roadways (Findlay et al. 2001, Gibbs 1998) and croplands devoid of wetlands or appropriate terrestrial habitat (Findlay et al. 2001, Kolozsvary and Swihart 1999, Lehtinen et al. 1999). Therefore, aside from loss of local habitat, reduction of the number of wetland habitats negatively affects dispersal by increasing inter-wetland distance and isolation (Semlitsch and Bodie 1998, Gibbs 1993). Semlitsch (1998) proposed that terrestrial habitat around wetlands (e.g. litter or canopy cover) should be protected within a 164 m radius. As well, uplands immediately surrounding wetlands provide critical foraging habitat for emerging young-of-year (YOY) and breeding adults of many terrestrial amphibians.

Wetlands drained by surface ditches can be easily re-flooded by stopping the outflow of water with an earth plug (Galatowitsch and van der Valk 1994), and when faced with other factors potentially causing a decline in amphibian populations (exotic species introduction, chemical contamination, climate change or disease) mitigating and restoring lost habitat is possibly the most feasible and cost-effective approach, and essential to recovery efforts (Semlitsch 2002, Reaser 2000).

There have been few published studies or reports focused on amphibians in the PPR (Clark et al. 1999, Lehtinen et al. 1999, Larson et al. 1998, Lannoo et al. 1994, Kantrud, Krapu and Swanson 1989), and only 2 known reports on amphibian use of restored wetlands. Sewell and Higgins (1991) found salamanders in restored wetlands (1-6 years post ditch plug construction) in a study of plant, waterfowl and fish (re)colonization in

Minnesota and North Dakota, U.S.A. Lannoo et al. (1994) and Galatowitsch and van der Valk (1994) reported that amphibians rapidly recolonize and breed in restored wetlands in the absence of fish or bullfrogs (*Rana catesbeiana*). Lannoo et al. (1994) also reported larger-bodied tiger salamander (*Ambystoma tigrinim*) larvae inhabiting restored versus natural wetlands due to cannibalistic behavior. It was speculated that this was caused by the fact that amphibians reached restored wetlands prior to the establishment of an invertebrate food base, although several studies have documented a variety of invertebrate taxa soon after restoration (Sewell and Higgins 1989, Delphey and Dinsmore 1993, Hemesath and Dinsmore 1993). To my knowledge no studies have intensively sampled restored prairie pothole wetlands for amphibians via pitfall and minnow trapping, and overall, knowledge of amphibian occurrence, abundance and habitat use in the northern PPR is poor.

This study took place in the Aspen Parkland Ecoregion, the northern one-third of the PPR distinguished by the presence of *Populus* spp., that has a harsh climate with a short growing seasons and low precipitation relative to other major agricultural areas of the world (Environment Canada 1996). There are 13 species of amphibians found within the PPR (Conant and Collins 1991, Galatowitsch and van der Valk 1994), but only 6 species that range as far north as the Parkland.

The heterogeneity of wetland habitat in the PPR is also critical for breeding waterfowl (Batt et al. 1989). Therefore, under the North American Waterfowl Management Plan initiative to improve upland and wetland habitat, Ducks Unlimited Canada (DUC) has restored more than 900 wetlands in Alberta, Saskatchewan and Manitoba since 1989 (Gray et al. 1999). To assess the success of restored wetlands as amphibian habitat, I compared amphibian occurrence and abundance in natural and restored wetlands in PPR wetlands of Alberta and Saskatchewan. The Alberta and Saskatchewan study sites were approximately 800 km apart, and allowed for the assessment of a habitat remediation technique in two key areas of DUC restoration activity in the PPR. This investigation was part of a larger study of plant (Chapter 2) and avian communities (Chapter 3, 4) in natural and restored wetlands. The life cycle and habitat needs of amphibians are dramatically different from wetland-dependent birds. Thus amphibian surveys provide additional information on the success of restored wetlands as functioning ecosystems. The present study addressed the following questions:

1) What species occur on comparable natural and restored wetlands in the PPR? Historical distributions suggest that wood frog (*Rana sylvatica*), Northern leopard frog, boreal chorus frog (*Pseudacris maculata*), Canadian toad (*Bufo hemiophrys*) and tiger salamander inhabit the Aspen Parkland of Alberta and Saskatchewan (Conant and Collins 1991). Additionally, Western toad (*Bufo boreas*) has recently become fairly common in Alberta near Elk Island National Park north of the present study site (S. Eaves, B. Eaton, University of Alberta, pers. commun. 2002).

2) Do patterns of amphibian species abundance differ between natural and restored wetlands, on a small, local scale based on trapping results or on a larger scale based on observational records? Are animals of similar size (snout-vent length, SVL) in natural and restored wetlands? Previous studies (Lannoo et al. 1994, Sewell and Higgins 1991) suggest that amphibians rapidly recolonize restored wetlands, and barring any extreme differences in the physical habitat of natural and restored wetlands, I predicted the existence of similar assemblages with comparable species abundance in natural and

restored wetlands. Although Lannoo et al. (1994) noted larger-bodied salamander larvae in recently restored wetlands, the wetlands of this study were not newly restored (3-7 years post flooding) and I predicted similar body sizes in natural and restored wetlands.

3) How is the abundance of amphibians related to the habitat features of prairie wetlands? Habitat features that I predicted to be important to amphibian assemblages include total surrounding wetland area (Semlitsch 2000, Gibbs 1993), the structure of wetland vegetation (Russell and Bauer 2000, Stratman 2000 IN Semlitsch 2002, Preston 1982) and local water chemistry (Hecnar and M'Closkey 1996, Glooschenko et al. 1992).

METHODS

Study Area

A total of 30 wetlands, within the Aspen Parkland Ecoregion of the Prairie Pothole Region (PPR) of Canada (Environment Canada 1996; Figure 2.1) were intensively sampled using traps (see surveys below). Eighteen wetlands were located within 50 km of Camrose, Alberta. Fourteen wetlands (7 restored) were surveyed in 1999 and 10 wetlands (5 restored) in 2000. Six wetlands (3 restored) were surveyed in both years of the study in order to assess annual variation. In 2000, an additional 12 wetlands were surveyed 100 km north of Foam Lake, Saskatchewan.

Wetland Selection

All selected wetlands were small (< 1.5 ha), fresh (<40-500 μS/cm) to slightly brackish (500-2000 μS/cm), seasonal (Class III) or semi-permanent (Class IV; Stewart and Kantrud 1971) and located on DUC purchase or lease property with surrounding uplands of planted cover. Fifteen wetlands surveyed were natural, relatively unaltered wetlands that served as reference sites. Natural wetlands were randomly selected from approximately 125 wetlands of similar size and permanence located on DUC properties in the area. Restored wetlands (15) were randomly selected from a pool of more than 400 similarly sized restored wetlands in the study area. Ditch plugs had been constructed by DUC engineering staff between 1989 and 1997 and were representative of the company's restoration efforts in time and scale. For construction details see Gray et al. (1999). Most of DUC's restoration activity (95%) occurred after 1992 (Gray et al. 1999) and this was reflected in the age of the wetlands surveyed (Appendices 1-3). The location of all surveyed wetlands within 20 m was referenced using Global Positioning System (GPS) and recorded in Universal Transverse Mercator (UTM) coordinates (northing and easting).

Surveys: Trap methodology

Amphibian assemblages were surveyed at each wetland from May until July (Alberta, May 25 to August 4, 1999, May 17 to July 29, 2000; Saskatchewan, May 23 to July 27, 2000) using two trapping techniques. Pitfall traps, constructed of 11.4 L plastic pails with polypropylene funnels, combined with drift fencing were used to capture terrestrially active amphibians (Heyer et al. 1994). Three (2000) or four (1999) arrays were distributed evenly around the wetland approximately 10 m from the wetland vegetation. Each array consisted of 2 lengths of 5 m polypropylene fence (~45 cm in height) arranged in a "V", open to the wetland (Figure 5.1). Each pail was buried so the lip was flush with the ground, and pails were placed at the ends and joint of the fences for a total of 3 pitfall traps per array. Thus, in 1999, there were 12 pitfall traps per wetland and in 2000 there were 9. Sticks were inserted in the buckets to allow small mammals to escape. Sponges were placed in each trap to provide moisture and cover for captured amphibians.

In order to survey adult and larval amphibians in open water habitat (and thus collect evidence of breeding), 3-4 minnow traps, baited with dry dog food, were deployed evenly throughout the wetland (Figure 5.1 c, Heyer et al. 1994). Trap funnels were submerged, but traps were placed to allow for breathing space for adults. This was accomplished by placing the traps in shallow water or by propping them in aquatic vegetation. Traps remained in the same location throughout the trapping season.

All traps were checked every 24-48 hours and all adult (individuals that had survived the previous winter) and young-of-the-year (YOY; individuals that metamorphosed in the current summer) amphibians were marked (by clipping 1 or 2 of their toes in a combination unique to the wetland of capture) and measured (SVL, mm). Toe clipping allowed recognition of recaptures. The number of trap nights (one trap open for one 24 hour period) per wetland is included in Appendices 4-6. A trap was considered non-functional and not included in trap night calculations when flooded or otherwise blocked. YOY were distinguished from adults by a shorter SVL (<29 mm after July) and remnant tail bud. For comparisons of catch-per-unit-effort (CPUE) in natural and restored wetlands and to explore amphibian habitat relationships, capture data for YOY and older individuals were combined and referred to as 'adult' (vs. larvae).

Surveys: Observational records

Amphibian presence or absence was also assessed based on sightings and calls during surveys of an additional 152 wetlands (82 restored) selected for a larger study of bird use in the same 2 study areas of Alberta in 2000 and Saskatchewan in 2000. Any frogs observed or heard calling were recorded during avian point counts conducted between sunrise and 10 am (Chapter 3, 4). In 1999, surveys in Alberta were conducted on 72 wetlands (39 restored) between May 23 and June 4 and a second time between June 18 and June 30. In 2000, 77 wetlands (39 restored) were surveyed in the same area between May 21 and June 3 and again from June 18 to July 4. A sub-set of the Alberta wetlands surveyed in 1999 (47, 22 restored) was surveyed again in 2000. For analyses of species occurrence in Alberta, the 2000 data and data for wetlands surveyed only in 1999 were combined to yield information on a total of 102 wetlands (56 restored). In Saskatchewan, bird surveys were conducted on 80 wetlands (41 restored) from May 21 to June 3, 2000 and a second time between June 18 and June 30, 2000.

Habitat characteristics

In order to describe local wetland habitat features related to successful amphibian reproduction and survival, I measured several parameters throughout the field season. Maximum wetland depth (cm, DEPTH) was recorded weekly using graduated stakes placed in the deepest part of the wetland. Conductivity (μS/cm, COND) or specific conductance was measured using a YSI model 33 S-C-T conductivity meter or a Corning model TDS-60 portable conductivity meter. Conductivity was measured *in situ* prior to wetland selection and twice during the field season in 1999, and weekly in 2000. Conductivity is highly correlated with water salinity (Wetzel 1983) and served as an affordable proxy measurement thereof. Water chemistry [chlorophyll$_a$ (μS/cm, CHLA), total phosphorus (μS/cm, TP) and pH (PH)] was measured once in June and again in July of each year. CHLA was only measured in 2000. The primary production and pH of a wetland can influence amphibian larval food sources and adult survival if tolerance limits are exceeded (Russell and Bauer 2000, Glooschenko et al. 1992, Freda and Dunson 1986, Wetzel 1983).

In 2000, the proportion of the wetland basin with plant cover (VEGCOVER) or inversely the amount of available open water habitat was recorded twice during the field season. In 1999, the proportion of vegetative cover was a visual estimate of the mean emergent band width (m, EMERG) rather than total basin cover. Emergent band width was the estimated width of the shallow marsh and deep marsh vegetation zones (Stewart and Kantrud 1971). The presence of vegetation in a wetland can be important for calling sites, oviposition sites and refuge (Russell and Bauer 2000).

Amphibians rely not only on aquatic habitats, but also on the surrounding terrestrial environment for foraging, dispersal and over-wintering (Semlitsch 2002, Gibbs 2000, Conant and Collins 1991). In order to quantify the immediately surrounding upland habitat, I estimated the height of surrounding upland vegetation approximately 20 m from the wetland edge in each cardinal direction (cm, UPHT). The landscape setting of each wetland was quantified by digitizing post-restoration air photos (1:30 000) obtained from DUC. Using Arcview 3.2 (ESRI 1992), the relative proportion of major habitat types were quantified within a 500 m radius of each surveyed wetland. Habitat types included woodland, wetland and cropland. Woodland (WOOD) was defined as habitat with woody vegetation (*Populus* spp., *Salix* spp., or conifers) with a vertical height ≥ 3 m. Wetland habitat (WETLAND) included natural and restored basins of all sizes and classes. Cropland (CROP) included areas that were tilled and planted to grain or row crops, as well as fields left to fallow. The distance (m) to the edge of the next nearest wetland (of any size, NEARWETL) and road (NEARROAD) were also recorded. Area

(m^2, AREA) for each surveyed wetland was also obtained from the digitized air photos. The boundary of a basin was determined by the transition from low prairie vegetation to planted cover. Habitat characteristics, abbreviations and means are listed in Table 5.1.

DATA ANALYSES

As 6 wetlands (3 restored) in Alberta were monitored over a 2-year period, preliminary analyses were conducted to determine inter-annual variation and explore combination of data from the 2 years in further analyses. Amphibian CPUE was compared for adults, YOY and larvae of each species encountered for the 6 wetlands surveyed in 1999 and 2000 using Mantel (PCOrd 4.0, McCune and Mefford 1999) and PROTEST analyses (MSDOS program, Jackson 1995). The Mantel test, which evaluates the null hypotheses of no relationship between 2 matrices, was performed using Monte Carlo randomization (1000 permutations) and Sorenson distance measures (McCune and Mefford 1999). As an additional evaluation of similarity, PROTEST was conducted comparing the first 5 Principal Components Analysis (PCA) axes scores for 1999 versus 2000 for wetlands surveyed in both years. PROTEST is proposed to be more powerful than Mantel tests as it uses randomization, but does not require the selection of appropriate distance measures (Jackson and Harvey 1993, Peres-Neto and Jackson 2001). As well, Mann-Whitney U-tests were used to compare abundance of common species between years in Alberta. A Mann-Whitney U-test is a non-parametric procedure used to test for differences between two populations (Systat 9.0, SPSS Inc. 1998, Zar 1999).

Results for pitfall CPUE indicated that catches for the 2 years were not concordant between 1999 and 2000 (Mantel r=0.009, p=0.47; PROTEST R=0.41, p=0.55). The results for minnow trap data were equivocal (Mantel r=-0.50, p=0.03; PROTEST R=0.26, p=0.13). However, as PROTEST is considered to be more powerful, I concluded that minnow trap catches also differed between years. Differences in CPUE were statistically significant for wood frogs (U=109.0, d.f.=1, p=0.02) and boreal chorus frogs (U=104.0, d.f.=1, p=0.05) captured in pitfall traps. Based on these differences, trapping results from Alberta in 1999 and 2000 were analyzed separately.

Using Mann-Whitney U-tests, differences in amphibian CPUE were compared between Alberta in 2000 and Saskatchewan in 2000 for each species and age class to assess geographic variation and wetland restoration in 2 areas of the PPR.

Restored versus natural wetlands

I used Mann-Whitney U-tests to compare differences in amphibian CPUE between natural and restored wetlands for each species and age class (adult, larvae) in each province and year (Alberta in 1999, Alberta in 2000, Saskatchewan in 2000; SYSTAT 9.0, SPSS Inc. 1998, Zar 1999). I compared differences in the frequency of amphibian occurrence records (presence/absence) in natural and restored wetlands in Alberta (102, 56 restored) and Saskatchewan (80, 41 restored) using Chi-square tests (Zar 1999).

I compared mean SVL for adult and YOY wood frogs and adult tiger salamanders captured in each province and year and boreal chorus frogs captured in Alberta in 1999 between natural and restored wetlands using t-tests (Zar 1999). For wood frogs, SVL was divided into individuals captured in May and June, and individuals capture in July post-YOY metamorphosis (adults and YOY). Insufficient captures of boreal chorus frogs in Alberta and Saskatchewan in 2000 precluded the comparison of SVL between natural and restored wetlands.

Habitat relationships

Due to the effort required to monitor amphibian populations in a given area, I intensively sampled relatively few wetlands in each province and year. The dynamics of prairie potholes and amphibian assemblages are highly variable. This variability combined with a small sample size precludes detailed analyses of species-habitat relationships using multivariate techniques. Therefore, in order to obtain a basic understanding of how habitat influences amphibian abundance, I used a combination of univariate techniques. Very few chorus frogs or salamanders were captured relative to trapping efforts, therefore investigation of habitat relationships was restricted to the wood frog.

To reduce the complexity and variability of the local and landscape habitat characteristic data, values for each variable were converted to discrete categories of high and low based on sample means. For example, mean depth in Saskatchewan was 43.0 cm, the high category included wetlands with mean depths of 43.1 cm and higher, and the low category included wetlands with depths of 0-43.0 cm.

I examined the influence of habitat on wood frog abundance for Alberta in 1999, Alberta in 2000 and Saskatchewan in 2000 by comparing CPUE (pitfall and minnow trap data) for high versus low habitat categories using Mann-Whitney U-tests. Box-and-whisker plots were constructed for CPUE for each habitat category (Figure 5.6-5.8; S-Plus 2000, Mathsoft 1999).

RESULTS

Species composition and trap results

A total of 4,086 adult and YOY amphibians were captured in 19,431 pitfall trap nights and 6,794 minnow trap nights (Appendices 4-6). Three species were present in surveys in both years and provinces; wood frog, boreal chorus frog, tiger salamander. Although the study area was within their historical ranges, Canadian toad, Western toad and Northern leopard frog were not captured at the 30 focal wetlands and there were no incidental observations or calls recorded for these species at any of the 182 sites.

Trapping results for all species captured on intensively sampled wetlands in each province and both years are summarized in Appendices 4-6. Wood frog adults were present in all intensively sampled wetlands in both years. Wood frog YOY and larvae were captured in almost all wetlands (>70% of wetlands in both sites and years). There were cases where I captured wood frog YOY, but I failed to capture larvae, or vice versa. Occurrence records suggested that wood frogs were not as frequent as indicated by trapping results. I recorded wood frog observations or calls on 27% of 102 Alberta wetlands and 29% of 80 Saskatchewan wetlands. This disparity may be related to the time of bird surveys relative to the brief period of peak spring calling for wood frogs.

Boreal chorus frogs (as adults, YOY or larvae) were captured in all intensively sampled wetlands in Alberta in 1999. In Alberta in 2000, a small number of chorus frogs (as adults, YOY or larvae) were captured on 8 of 10 wetlands. Similarly, I captured 10 individuals in Saskatchewan in 6 wetlands (3 restored), and larvae were captured in 10 wetlands (6 restored). Although, boreal chorus frogs were rare in pitfall and minnow trap captures in both provinces, occurrence records (animals seen or heard) for 182 wetlands suggest that chorus frogs are fairly common. (44% of 102 Alberta wetlands in 1999 and 2000 combined, and 53% of 80 Saskatchewan wetlands in 2000).

Trapping efforts succeeded in capturing adult tiger salamanders in 53% of wetlands in Alberta in 1999, 80% in Alberta in 2000, and 83% in Saskatchewan in 2000. Minnow traps were the most effective means of surveying adult and larval tiger salamanders. I captured 27 larvae total in natural wetlands, exclusively. Salamanders do not vocalize to allow documentation via call surveys and I saw no salamanders outside of traps.

Overall, recapture rates of marked animals were low. In Alberta in 1999, recapture rates were 8.8% for wood frogs (25 individuals) and 2.6% for salamanders (1), and in 2000, it was 4.4% for wood frogs (7) and 31.4% for salamanders (16). Rates were similar in Saskatchewan, where 2.3% wood frogs (42) and 21.3% of salamanders (17) were recaptured. No chorus frogs were recaptured. All animals had been marked with a toe-clipping pattern that was unique to each surveyed wetland and I found that all recaptures were on the original wetland.

As indicated, pitfall trap CPUE for wood frog and boreal chorus frog (adults and YOY) in Alberta was higher in 1999 than 2000 (Table 5.2). One restored wetland in Alberta (Coykendall 55) was a productive breeding site for wood frogs in 1999 (24 YOY and 229 larvae), but I only captured 1 YOY in 2000. This wetland was dry for much of June (mean depth <5 cm) making this site unsuitable for breeding. Chorus frogs were not captured on 2 natural wetlands in 2000 where they had been previously captured in 1999. New captures in 2000 included wood frog larvae on one natural and one restored wetland, and an adult salamander on 1 natural wetland where these species were not observed in 1999.

In 2000, there were significantly greater numbers of adult and YOY wood frogs (combined) in Saskatchewan compared to Alberta (pitfall trap data, U=1.0, d.f.=1, p=0.0; minnow trap data, U=9.0, d.f.=1, p=0.001; Table 5.2). Although few chorus frogs were captured in either province, there was a greater pitfall capture rate in Alberta than Saskatchewan in 2000 (U=90.0, d.f.=1, p=0.02). Salamander capture rates were similar between provinces.

Restored versus natural wetlands

CPUE for pitfall and minnow trap for all species and age classes was comparable in restored versus natural wetlands in Alberta in 1999 (Figure 5.2, Table 5.3) and Saskatchewan in 2000 (Figure 5.4a, b, Table 5.3). This trend did not continue in Alberta in 2000. There was lower pitfall trap CPUE for adult boreal chorus frogs (Figure 5.3, Table 5.3; U=2.0, d.f.=1, p=0.02) and higher minnow trap CPUE for tiger salamanders (U=22.0, d.f.=1, p=0.05) in natural wetlands. Wood frogs were captured in similar numbers in natural and restored wetlands in Alberta in 2000.

Frequency of occurrence recorded during avian point counts of wood frogs and boreal chorus frogs was similar between natural and restored wetlands (Figure 5.5; Alberta, boreal chorus frog, χ^2=0.17, d.f.=1, p=0.89, wood frog, χ^2=0.12, d.f.=1, p=0.87; Saskatchewan, boreal chorus frog, χ^2=0.0001, d.f.=1, p=0.97, wood frog, χ^2=0.12, d.f.=1, p=0.87).

In both years of study in Alberta, wood frog adults captured in May and June were significantly larger in restored wetlands than natural wetlands (Table 5.4). Adult and YOY wood frogs captured in restored wetlands in Alberta in July of 1999 were also significantly larger than frogs captured in natural wetlands. The mean SVL for wood frogs captured in July in Alberta in 2000 and for wood frogs captured in both time periods in Saskatchewan did not differ significantly between wetland types. Tiger salamanders captured in natural and restored wetlands had similar SVL in both provinces and years (Table 5.4). In Alberta in 1999, boreal chorus frogs had similar SVL in natural and restored wetlands (Table 5.4). There were too few boreal chorus frogs captured in 2000 to compare body size between natural and restored wetlands. Size-frequency distributions for wood frogs and tiger salamanders for each year and province are included in Appendices 7-10.

Wood frog-habitat relationship

Table 5.1 summarizes the results for all CPUE – habitat category comparisons for wood frogs. Analysis of pitfall traps versus minnow traps often resulted in different habitat relationships. In Alberta in 1999, three habitat characteristics (divided into discrete categories of high and low) appeared to influence wood frog CPUE (Figure 5.6). Pitfall trap CPUE was higher on wetlands with a wider band of emergent vegetation (>3.4 m, EMERG; U=5.0, d.f.=1, p=0.01) and on deeper wetlands (>46.3 m, DEPTH; U=8.0, d.f.=1, p=0.04). Minnow trap CPUE was higher on wetlands with a greater proportion of wetland habitat in the surrounding region (>14.0%, WETL; U=7.0, d.f.=1, p=0.03). In Alberta in 2000, minnow trap CPUE was higher on smaller wetlands (<2874.5 m^2, AREA; U=20.0, d.f.=1, p=0.03, Figure 5.7). Pitfall and minnow trap CPUE in Saskatchewan resulted in more consistent habitat relationships (Table 5.1, Figure 5.8). In Saskatchewan in 2000, pitfall trap CPUE and minnow trap CPUE was higher in wetlands with shorter stem height in upland vegetation (<37.7 m, UPHT) and in wetlands with a greater proportion of woodland in the surrounding area (>14.6%, WOOD).

DISCUSSION

Of the three species documented in prairie pothole wetlands, wood frogs were the most abundant in Alberta and Saskatchewan. Boreal chorus frogs and tiger salamanders were also observed, but in fewer numbers and not in all wetlands. Wood frogs were captured in all 30 focal wetlands, but were heard or observed in <30% of 182 wetlands also surveyed for birds. Wood frogs typically begin calling immediately following snow melt in the spring and chorusing may only last 1-2 weeks in early May (Russell and Bauer 2000, A. Puchniak, personal observation). As call surveys were conducted in late May and June, occurrence records may be not reflect the true frequency of occurrence in Prairie wetlands.

The small number of boreal chorus frogs captured was probably not an accurate measure of their abundance in Alberta and Saskatchewan, as their calls were frequently heard in the spring and incidental observations documented chorus frogs in almost half the wetlands surveyed for birds (182, 97 restored). Chorus frogs are hylids that are equipped with sticky toe pads and a small body weight that facilitates their escape from pitfall traps (Conant and Collins 1991). Adults and larvae are small enough to squeeze through the mesh of minnow traps, although chorus frogs were rarely observed in open water habitat outside of the breeding season (A. Puchniak, personal observation).

The absence of tiger salamanders in some wetlands may be related to a lack of suitable overwintering sites nearby (e.g. pocket gopher burrows; Preston 1982) and the absence of larvae in restored wetlands (recently flooded habitat) may be related to the tendency for amphibians to return to the same breeding sites each year (Semlitsch 1983). My records of salamanders in Alberta and Saskatchewan likely underestimated abundance, because I could not record salamanders using call surveys and needed to rely solely on trapping techniques as adults are primarily noctural and seldom seen.

The higher number of salamanders in Alberta in 2000 and one natural wetland in Saskatchewan in 2000 (Loshka) may have contributed to the reduction or absence of larval anuran populations, as salamanders are known predators on tadpoles (Conant and Collins 1991). However, we observed no evidence of reduced wood frog abundance in wetlands with adult tiger salamanders present (A. Puchniak, unpublished data).

I observed substantial variation in amphibian populations between years in Alberta wetlands. For example, I captured fewer adult and YOY wood frogs and boreal chorus frogs in 2000. This year was the beginning of a drought period in Alberta (mean annual total precipitation=466 mm, 1999=454.4 mm, 2000=388.9 mm; average maximum July temperature=22.5 °C, in 1999=20.17 °C, 2000=15.32 °C; Environment Canada climate information 2000), and the reduced precipitation and snowfall probably negatively affected frog populations. Reduced snow cover over the winter (1999-2000) may have reduced the insulating layer for hibernating wood frogs and other species and may reduce over-winter survival of adults and absolute numbers of captures. All 6 wetlands surveyed in 1999 and 2000 had lower depths in the second year of study. Many wetlands in the area were dry in the spring or shortly thereafter, and fewer larvae were captured per wetland early in the spring, resulting in a reduced number of YOY in July.

The dynamic nature of prairie wetlands results from a fluctuating water regime caused by extreme climatic variation (Kantrud, Millar and van der Valk 1989). Annual variation in spring run-off, summer precipitation and evapotranspiration results in fluctuations in water levels (Murkin et al. 2000). This wet-dry cycle (van der Valk and Davis 1978) can result in major shifts in plant species communities and consequently wildlife assemblages (Kantrud, Millar and van der Valk 1989). Although my surveys only took place over a two-year period, 2000 was the beginning of a dry period and reduced wood and chorus frog captures reflected its onset.

I encountered no evidence of Canadian toads, western toads or northern leopard frogs. Historically, Canadian toads were widely distributed in the prairies, aspen parkland and boreal forest, but visual or call records have been declining in recent years possibly due to loss of wetland habitat (Conant and Collins 1991, Russell and Bauer 2000). The species is ranked as 'may be at risk' in Alberta (Alberta Environment 2000) and my surveys support this listing. Canadian toad is listed as 'apparently secure' in Saskatchewan, but my survey and those of Clark et al. (1999) have no positive records of the species, and perhaps its current listing in Saskatchewan should be further investigated. Western toads are secure within their range in western Alberta (Russell and Bauer 2000) and their recently documented presence in the Aspen Parkland in Elk Island National Park may be evidence of an eastward range expansion (Eaton et al. 1999). However, my wetlands may still be outside of the species' current range. Northern leopard frogs are considered 'at risk' in Alberta (Alberta Environment 2000) and are listed as 'vulnerable' in Saskatchewan (Saskatchewan Conservation Data Centre 1998). The species occurrence in Alberta has been reduced to a few small, fragmented populations; wetland loss and isolation were a major source of their decline. I found no published records of leopard frog status and recent occurrence in Saskatchewan. The prairie populations of leopard frogs were nationally listed as one of 'special concern' in 1999 (Seburn and Seburn 2000).

Greater wood frog abundance and lower boreal chorus frog abundance in Saskatchewan suggested some geographic variation in habitat conditions. The area surrounding the Saskatchewan wetlands was not subjected to the same drought conditions experienced in Alberta in 2000 (Agriculture Canada 2002; mean total annual precipitation in Alberta=466 mm, 2000=388.9 mm; mean total annual precipitation in Saskatchewan=347 mm, in 2000=414 mm; Environment Canada climate information 2000). Differences in precipitation patterns probably resulted in different over-wintering and spring-breeding conditions between the provinces.

All amphibian species and age classes were captured in similar frequency in natural and restored wetlands in Alberta in 1999 and Saskatchewan in 2000, supporting my predictions. The most abundant species, wood frog, was also observed in similar frequency in natural and restored wetlands in Alberta in 2000 and observational records at a large number of wetlands support these findings.

Although wood frogs were captured in comparable abundance in wetland types in Alberta, I captured larger wood frogs in restored wetlands, and this difference in body size was not predicted. These findings warrant further investigation of food resources available and predatory or competitive influences in restored wetlands. Lannoo et al. (1994) had documented larger-bodied tiger salamander larvae in restored wetlands and related these differences to cannibalism to a reduced invertebrate food source in restored wetlands in Iowa.

Overall, adult wood frogs captured in natural and restored wetlands in Alberta in 1999 (Table 5.4) were comparable to breeding wood frogs captured in southern Quebec, Canada (males $\bar{x}$=43.6 ± 2.0 mm, females $\bar{x}$=48.8 ± 2.7 mm, Sagor et al. 1998) and

Maryland (first year breeding females $\bar{x}$=45.2 ± 1.1 mm, Berven 1988). Wood frogs captured in Alberta in 2000 and Saskatchewan in 2000 had shorter SVL than these eastern studies (Table 5.4). All wood frogs of this study were within the range of breeding individuals in boreal Alberta (29-56 mm, Roberts and Lewin 1979) and southern Michigan (26-44 mm, Heatwole 1961), but again many individuals captured in Alberta in 2000 and Saskatchewan in 2000 were closer to the size range of reported 1-year old animals (20-31 mm, Roberts and Lewin 1979). Smaller sized wood frogs in 2000 may reflect the colder temperatures and short growing season of the Prairies, but as SVL is proportional to age, results may also reflect a different age structure in these populations with more young animals (Sagor et al. 1998) and strong recruitment in 1999.

Boreal chorus frog pitfall trap CPUE was lower in natural wetlands in Alberta in 2000. However, the overall small sample sizes and small number of sites warrant caution in interpretation of the findings that assemblages were different in Alberta wetlands. Call surveys at a large number of wetlands in Alberta and Saskatchewan in 1999 and 2000 suggest that breeding boreal chorus frogs actually occurred in similar frequency in natural and restored wetlands. Chorus frogs captured in Alberta in 1999 also had similar body sizes between wetland types. In general, boreal chorus frogs captured had comparable SVL (Table 5.8) to breeding adults in northern Alberta (19.3-28.2 mm, Roberts and Lewin 1979).

Tiger salamanders were captured at similar rates in natural and restored wetlands in Saskatchewan in 2000. A trend toward greater tiger salamander CPUE in natural versus restored wetlands was seen in Alberta in 1999, and this trend was significantly different in 2000. As discussed earlier, amphibians may return each year to the same wetland to breed and this behavior may have resulted in the apparent absence of salamander breeding in restored wetlands (Russell and Bauer 2000). Differences may also be related to local wetland or landscape features that are unrelated to wetland drainage history, such as the availability of suitable overwintering sites. Semlitsch (1983) found that annual variation in climatic conditions and characteristics typical of ephemeral breeding wetlands accounted for much of the variation in the number of breeding adults at a site. Reports in the United States have found that salamanders readily colonize and breed in restored wetlands (Galatowitsch and van der Valk 1994, Lannoo et al. 1994) and Sewell and Higgins (1991) captured salamanders in minnow traps and activity traps in restored wetlands 1-6 years post-restoration (re-flooding). Trapping results for Alberta in 1999 and Saskatchewan in 2000 also indicated that tiger salamanders were present in restored wetlands in numbers comparable to nearby natural wetlands. Future research in restored wetlands will need to address whether an apparent absence of salamander breeding was due to inadequate sampling or the absence of characteristics in restored wetlands needed for reproduction.

Unlike Lannoo et al. (1994)'s findings, tiger salamanders had comparable SVL in natural and restored wetlands in both sites and years. Adult salamanders captured in Alberta in 1999 were similar to the SVL of individuals captured in South Carolina, U.S.A. ($\bar{x}_{males}$=94.1 ± 0.4 mm, $\bar{x}_{females}$=95.5 ± 0.5 mm, Semlitsch 1983), whereas individuals captured in Alberta in 2000 and Saskatchewan in 2000 were slightly smaller. Again, the smaller individuals in 2000 may reflect predominance of young individuals and strong recruitment in 1999.

Chorusing in the spring and the presence of larvae and YOY in restored wetlands, indicated that wood frogs and boreal chorus frogs successfully bred in restored wetlands. Wood frog YOY emerging from restored basins in Alberta in 1999 were slightly larger and future studies should compare the food resources in restored wetlands to determine if there are differences in availability or abundance that may contribute to the differences in body sizes.

Pitfall and minnow trap captures of wood frogs did not indicate the same relationships between frog densities and habitat characteristics. Differences likely reflect differences in trap techniques and variation in the catchability and activity of the species between aquatic and terrestrial habitats (Mitchell et al. 1993). As well, significant habitat characteristics were not consistent between provinces or years, possibly indicating annual or geographic variation in wood frog responses. The relationships uncovered, however, were obtained from a small number of sites and based on categorical data.

I found some support for my habitat relationship predictions, as local features relating to wetland vegetation and the proportion of surrounding wetlands habitat in the landscape had some influence on wood frog abundance. Wood frogs were captured in greater abundance in wetlands with a greater proportion of emergent vegetation (EMERG, Alberta in 1999, pitfall trap CPUE) and shorter surrounding upland habitat (UPHT, Saskatchewan in 2000, pitfall and minnow trap CPUE) reflecting the importance of wetland vegetation for oviposition, chorusing and refuge (Russell and Bauer 2000) and upland vegetation for terrestrial foraging (Galatowitsch and van der Valk 1994). All surveyed wetlands had surrounding uplands of permanent planted cover, and shorter, less dense upland vegetation may provide more open habitat for small, opportunistic visual foragers such as anurans (Zug 1993).

As size and depth are often correlated in prairie wetlands (Kantrud and Stewart 1984), the importance of deeper (DEPTH, Alberta in 1999, pitfall trap CPUE), smaller (AREA, Alberta in 2000, minnow trap CPUE) wetlands may appear contradictory. However, I observed substantial annual variation in the abundance of wood frogs in Alberta wetlands, and this may be reflected in the habitat relationships that resulted. There is a trade-off for amphibians to choose between deeper, larger wetlands with a longer hydroperiod to ensure larval metamorphoses and shallower, less permanent wetlands that are less likely to support a predator assemblage (e.g. diving beetles; Skelly 1997, Heatwole 1961) and there may be annual variation that accompanies this habitat selection. However, It should be noted that the range of wetland sizes in this study was small and none contained fish.

The significance of landscape features such as the proportion of surrounding wetland (WETLAND, Alberta in 1999, minnow trap CPUE) and woodland habitat (WOOD, Saskatchewan in 2000, pitfall and minnow trap CPUE) reflected the importance of the terrestrial habitat and connectivity of potential habitat patches. Wood frogs are aptly named for the proportion of time spend foraging and overwintering in the moist habitats of nearby woodlands, and their increased abundance in areas with greater woodland cover was not surprising (Roberts and Lewin 1979, Heatwole 1961, Waldick et al. 1999, Werner and Glennemeier 1999, Guerry and Hunter 2002).

Analysis of the size and distribution of smaller wetlands (<2-5 ha) indicates that these wetlands comprise a large proportion of the total wetland area on most landscapes (i.e.

most wetlands are small) and are important for the connectivity between wetland habitats (distance between wetlands; Gibbs 1993, 2000, Semlitsch and Bodie 1998). Small wetlands (<1 ha, <1.5 m in depth) are not likely to support fathead minnow (*Pimphales promelas*) and brook stickleback (*Culaea inconstans*), which are the only fish that can typically tolerate the low oxygen conditions and annual variation of deeper pothole wetlands (>1.5-5 m, Peterka 1989). Not only are they predators, small bodied fish such as these may be a source of competition (B. Eaton, University of Alberta, pers. commun. 2001), and fishless wetlands may provide refuges for breeding amphibians. Small wetlands in particular, are easily drained using modern equipment (Gray et al. 1999) and are not protected under current wetland management government policies (Gibbs 1993, 2000, Semlitsch and Bodie 1998, H. Murkin, Ducks Unlimited Canada, pers. commun., 2001). Studies have shown that continued loss of small wetlands (<0.8 ha) could eventually increase inter-wetland distance beyond mean dispersal distances for amphibians (>300 m, Gibbs 2000). Managers will need to take into account the basin size and distance between restored wetlands when improving habitat for amphibians.

Overall, Class III and IV restored wetlands are providing suitable habitat for amphibians in Prairie Canada. Amphibian abundance was similar between natural and restored wetlands in Alberta and Saskatchewan. Wood frogs and boreal chorus frogs successfully breed in restored wetlands. Future research should include investigation into the apparent absence of salamander breeding in restored wetlands and larger wood frog body sizes there. Survey techniques produced different results regarding the abundance or occurrence of species, and ideally future monitoring would include multiple techniques as time and effort permit. In order to successfully mitigate wetland loss for amphibians, managers must take into account local features (e.g. wetland permanence and area) and landscape features (e.g. upland habitat) when planning future restorations.

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Table 5.1: A summary of wood frog pitfall trap and minnow trap catch-per-unit-effort comparisons for habitat characteristics categorized into high and low categories by the mean. A total of 30 wetlands were surveyed; 14 wetlands in Alberta 1999, 10 wetlands in Alberta 2000, and 12 wetlands in Saskatchewan 2000.

		Alberta 1999					Alberta 2000					Saskatchewan 2000				
		Mean	Pitfall trap		Minnow trap		Mean	Pitfall trap		Minnow trap		Mean	Pitfall trap		Minnow trap	
Habitat Characteristic			U statistic	p	U statistic	p		U statistic	p	U statistic	p		U statistic	p	U statistic	p
DEPTH	maximum wetland depth (cm)	46.2	**8.0**	**0.04***	31.0	0.37	40.0	11.0	0.83	16.0	0.39	43.0	24.0	0.29	23.0	0.37
UPHT	upland height within 10 m (cm)	59.6	20.0	0.74	20.0	0.74	62.9	4.0	0.30	14.0	0.12	37.7	30.0	0.06	**33.0**	**0.02***
VEG COVER	proportion of vegetative cover on basin (%)		n/a				67.3	17.0	0.29	6.0	0.20	63.5	7.0	0.13	19.0	0.26
EMERG	emergent vegetation band width (m)	3.4	**5.0**	**0.01***	25.0	0.90		n/a					n/a			
CROP	proportion of cropland within 500 m radius (%)	24.0	18.0	0.44	36.0	0.12	22.8	12.0	0.92	12.0	0.92	23.7	21.0	0.63	22.0	0.52
WETLAND	proportion of wetland habitat within 500 m radius (%)	14.0	18.0	0.41	**7.0**	**0.03***	12.3	10.0	0.67	15.0	0.52	15.2	21.0	0.63	28.0	0.11
WOOD	proportion of woodland within 500 m radius (%)	7.4	18.0	0.78	24.0	0.57	7.1	7.0	0.29	11.0	0.83	14.6	**4.0**	**0.03***	**1.0**	**0.01***
AREA	wetland area (m2)	2024.3	14.0	0.26	26.0	0.64	2874.5	11.0	0.91	**20.0**	**0.03***	3511.0	12.0	0.37	20.0	0.69
NEAR ROAD	next nearest road (m)	340.0	18.0	0.41	23.0	0.85	400.6	10.0	0.60	4.0	0.08	426.6	16.0	0.75	10.0	0.20
NEAR WETL	next nearest wetland (m)	37.7	17.0	0.46	16.0	0.39	48.4	7.0	0.43	16.0	0.21	54.7	14.0	0.73	23.0	0.23
TP	total phosphorus (μg/L)	898.7	33.0	0.25	19.0	0.52	2029.8	10.0	0.60	7.0	0.79	197.4	22.0	0.52	21.0	0.63
CHLA	chlorophyll a (μg/L)		n/a				107.0	8.0	0.57	14.0	0.43	32.1	12.0	0.50	16.0	1.00
COND	conductivity (μS/cm)	468.3	20.0	0.74	31.0	0.26	883.7	14.0	0.67	12.0	1.00	792.1	11.0	0.29	17.0	0.94
PH	pH	7.3	18.0	0.44	31.0	0.37	7.9	9.0	0.47	15.0	0.60	8.2	29.0	0.08	17.0	0.87

Table 5.2: The results of a comparison of catch-per-unit-effort of amphibians in Alberta wetlands trapped in 1999 versus 2000, and the results of comparison between wetlands sampled in Alberta versus Saskatchewan in 2000. Comparisons were made using Mann-Whitney U-tests with 1 degree of freedom. Wetlands were surveyed using minnow and pitfall traps and CPUE was analysed separately for the 2 trap types. YOY = young-of-the-year, n/a = no animals were trapped by that technique. Significant results are marked with *.

Comparison between years in Alberta

			Pitfall trap CPUE			Minnow trap CPUE		
	Year	No. of wetlands	Rank sum	U-statistic	p	Rank sum	U-statistic	p
Wood frog adults and YOY	1999	14	214	109	0.02 *	185	80	0.56
	2000	10	86			115		
Wood frog larvae	1999	14	n/a			174	69	0.95
	2000	10				126		
Boreal chorus frog adult and YOY	1999	10	209	104	0.05 *	n/a		
	2000	14	91					
Boreal chorus frog larvae	1999	14	n/a			181	76	0.72
	2000	10				119		
Tiger salamander adult	1999	14	162	57	0.38	154	49	0.20
	2000	10	138			146		
Tiger salamander larvae	1999	14	n/a			169	64	0.59
	2000	10				131		

Comparison between provinces

			Pitfall trap CPUE			Minnow trap CPUE		
	Province	No. of wetlands	Rank sum	U-statistic	p	Rank sum	U-statistic	p
Wood frog adults and YOY	Alberta	10	56	1	0.00 *	64	9	0.00 *
	Saskatchewan	12	197			189		
Wood frog larvae	Alberta	10	n/a			91	36	0.11
	Saskatchewan	12				162		
Boreal chorus frog adult and YOY	Alberta	10	145	90	0.02 *	105	50	0.19
	Saskatchewan	12	108			148		
Boreal chorus frog larvae	Alberta	10	n/a			99	44	0.28
	Saskatchewan	12				154		
Tiger salamander adult	Alberta	10	121	66	0.21	114	59	0.95
	Saskatchewan	12	132			139		
Tiger salamander larvae	Alberta	10	n/a			123	68	0.38
	Saskatchewan	12				130		

Table 5.3: Results from Mann-Whitney U-test comparisons of catch-per-unit-effort (CPUE) between natural and restored wetlands based on 2 trapping techniques near Camrose, Alberta in 1999 and 2000 and Foam Lake, Saskatchewan in 2000. Alberta 1999 had 14 wetlands (7 restored), Alberta 2000 had 10 wetlands (5 restored) and Saskatchewan 2000 had 12 wetlands (6 restored). All comparisons had 1 degree of freedom. Significant results are marked with *. YOY = young-of-the-year, n/a = no animals trapped by that technique.

		Pitfall trap CPUE			Minnow trap CPUE		
	Wetland type	Ranksum	U-statistic	p	Ranksum	U-statistic	p
Alberta 1999							
Wood frog adult and YOY	Natural	49	21	0.655	50	22	0.75
	Restored	56			55		
Wood frog larvae	Natural	n/a			44.5	16.5	0.30
	Restored				60.5		
Boreal chorus frog adult and YOY	Natural	42	14	0.18	52.5	24.5	1.00
	Restored	63			52.5		
Boreal chorus frog larvae	Natural	n/a			39.5	11.5	0.08
	Restored				65.5		
Tiger salamander adult	Natural	62	34	0.157	55.5	27.5	0.67
	Restored	43			49.5		
Tiger salamander larvae	Natural	n/a			59.5	31.5	0.14
	Restored				45.5		
Alberta 2000							
Wood frog adult and YOY	Natural	26	11	0.754	27	12	0.92
	Restored	29			28		
Wood frog larvae	Natural	n/a			26.5	11.5	0.83
	Restored				28.5		

		Pitfall trap CPUE			Minnow trap CPUE		
	Wetland type	Ranksum	U-statistic	p	Ranksum	U-statistic	p
Boreal chorus frog adult and YOY	Natural	17	2	0.024 *	27.5	12.5	1.00
	Restored	38			27.5		
Boreal chorus frog larvae	Natural	n/a			25	10	0.59
	Restored				30		
Tiger salamander adult	Natural	27.5	12.5	1	37	22	0.05 *
	Restored	27.5			18		
Tiger salamander larvae	Natural	n/a			32.5	17.5	0.14
	Restored				22.5		
Saskatchewan 2000							
Wood frog adult and YOY	Natural	36	15	0.631	43	22	0.52
	Restored	42			35		
Wood frog larvae	Natural	n/a			33	12	0.34
	Restored				45		
Boreal chorus frog adult and YOY	Natural	38.5	17.5	0.902	39.5	18.5	0.90
	Restored	39.5			38.5		
Boreal chorus frog larvae	Natural	n/a			35	14	0.52
	Restored				43		
Tiger salamander adult	Natural	44.5	23.5	0.295	39	18	1.00
	Restored	33.5			39		
Tiger salamander larvae	Natural	n/a			42	21	0.32
	Restored				36		

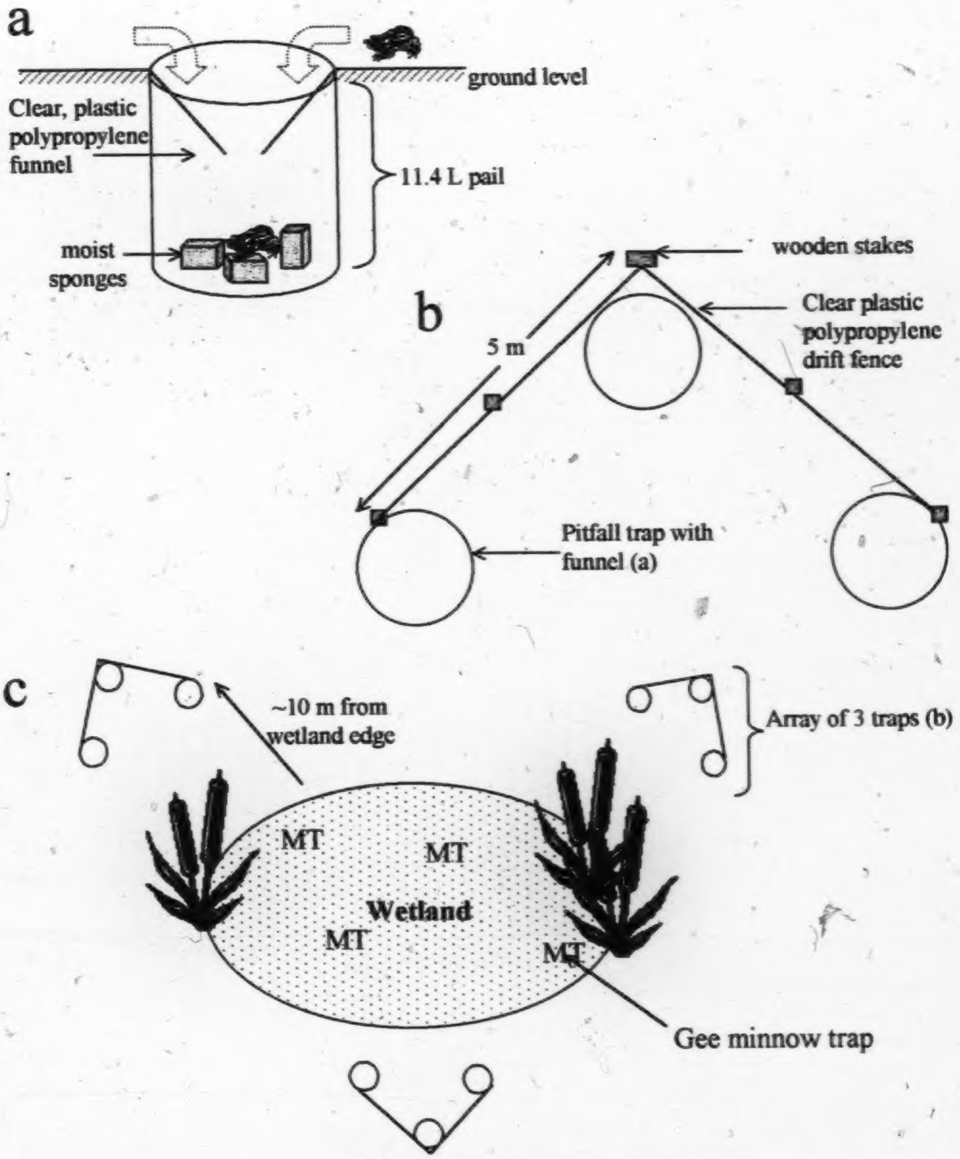

a
ground level
Clear, plastic polypropylene funnel
11.4 L pail
moist sponges
wooden stakes
b
Clear plastic polypropylene drift fence
5 m
Pitfall trap with funnel (a)
c
~10 m from wetland edge
Array of 3 traps (b)
MT
MT
Wetland
MT
MT
Gee minnow trap

Figure 5.1: Diagram illustrating the trap methodology for Prairie Pothole wetlands in Alberta and Saskatchewan. a. single pitfall trap and funnel b. array of 3 pitfall traps c. orientation of pitfall and minnow traps around a wetland.

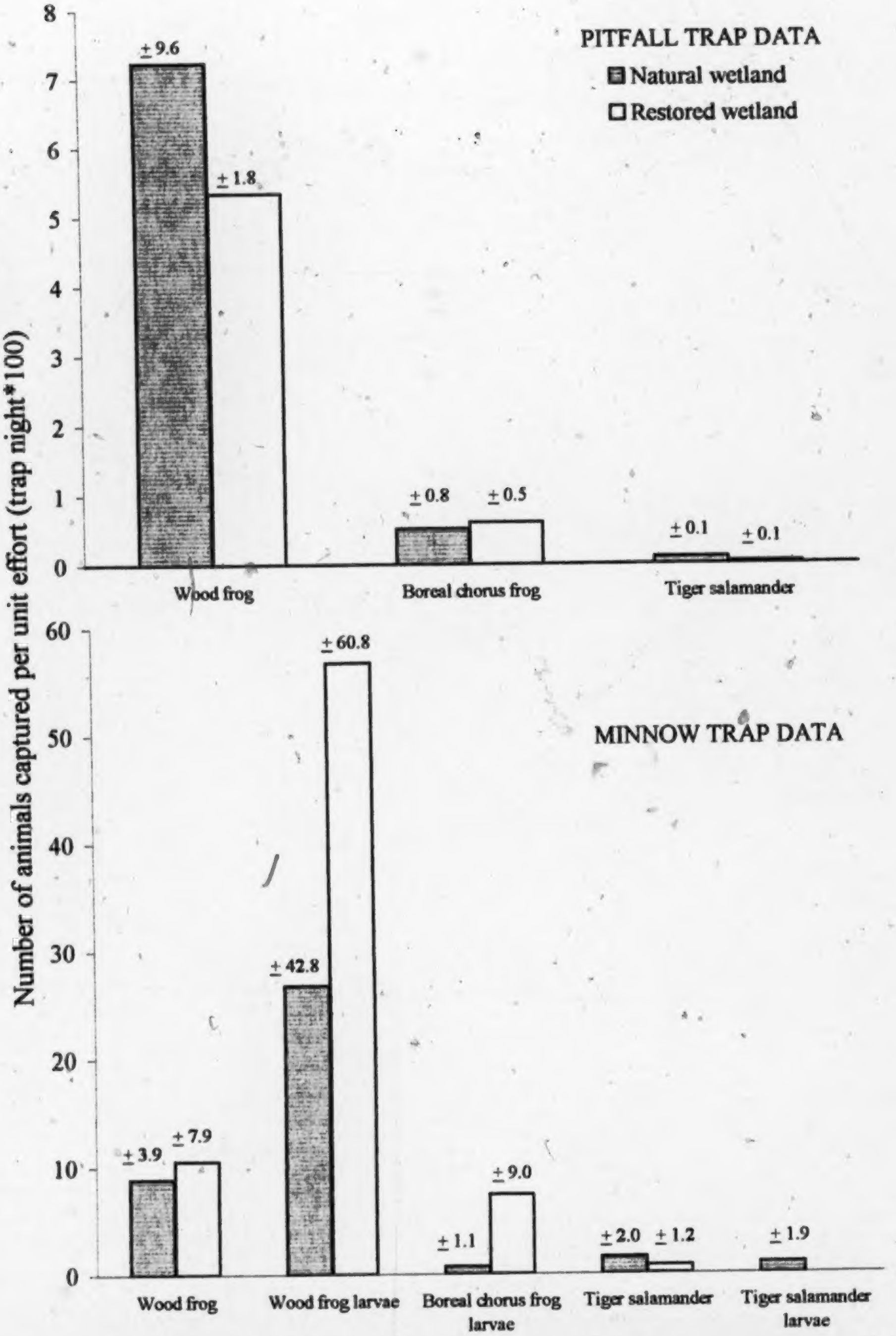


Figure 5.2: A comparison of catch per unit effort rates in 7 natural and 7 restored wetlands for adults and young-of-year and for larvae of 3 species captured in minnow and pitfall traps near Camrose, Alberta, Canada 1999. Numbers represent 1 standard deviation. Comparisons were made using Mann-Whitney U- tests and none were significantly different.

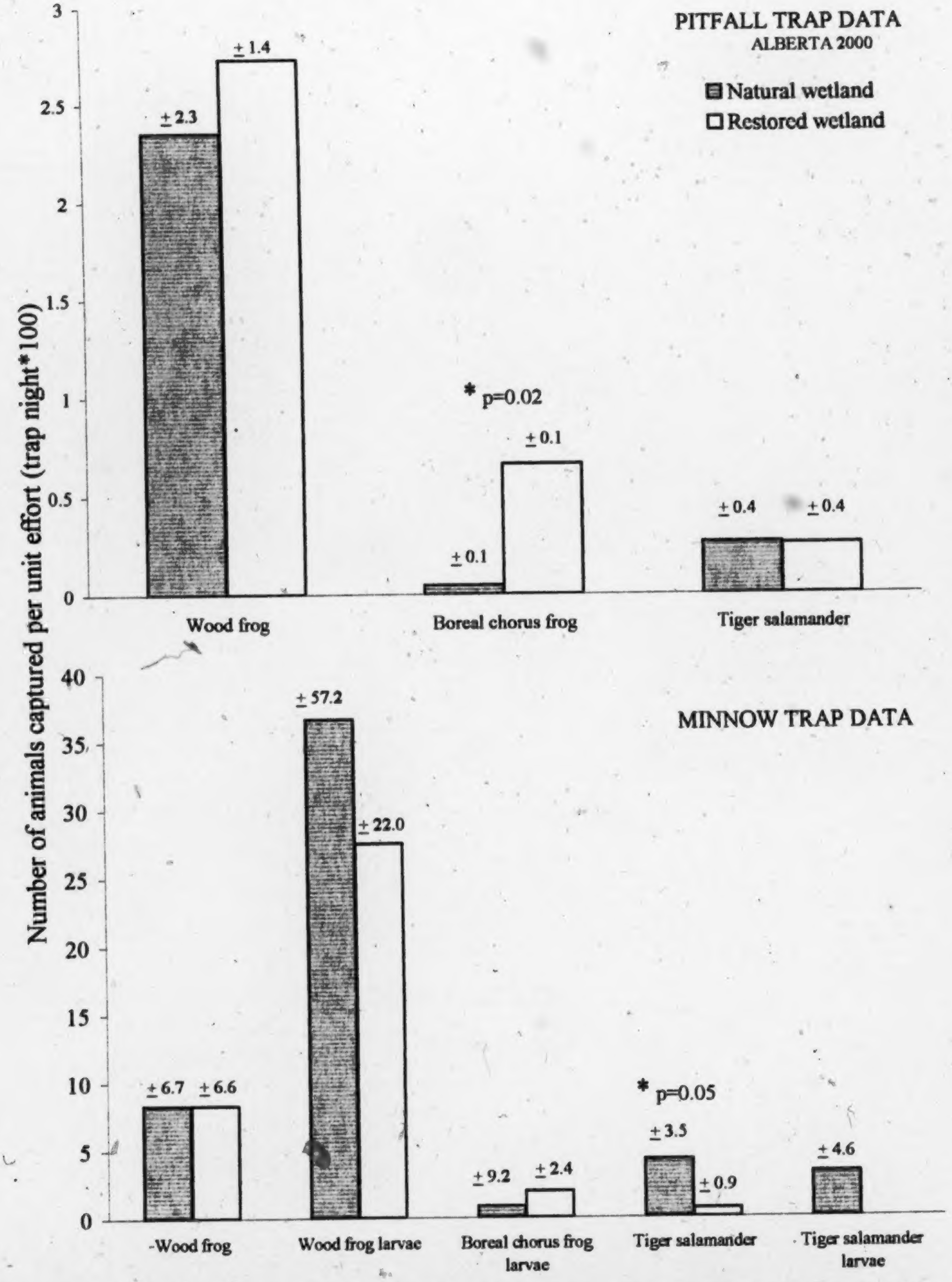


Figure 5.3: A comparison of catch per unit effort rates in 5 natural and 5 restored wetlands for adults and young-of-year and for larvae of 3 species captured in minnow and pitfall traps near Camrose, Alberta, Canada 2000. Numbers represent 1 standard deviation. Comparisons were made using Mann Whitney U-tests and significant results are marked with * and corresponding p-value.

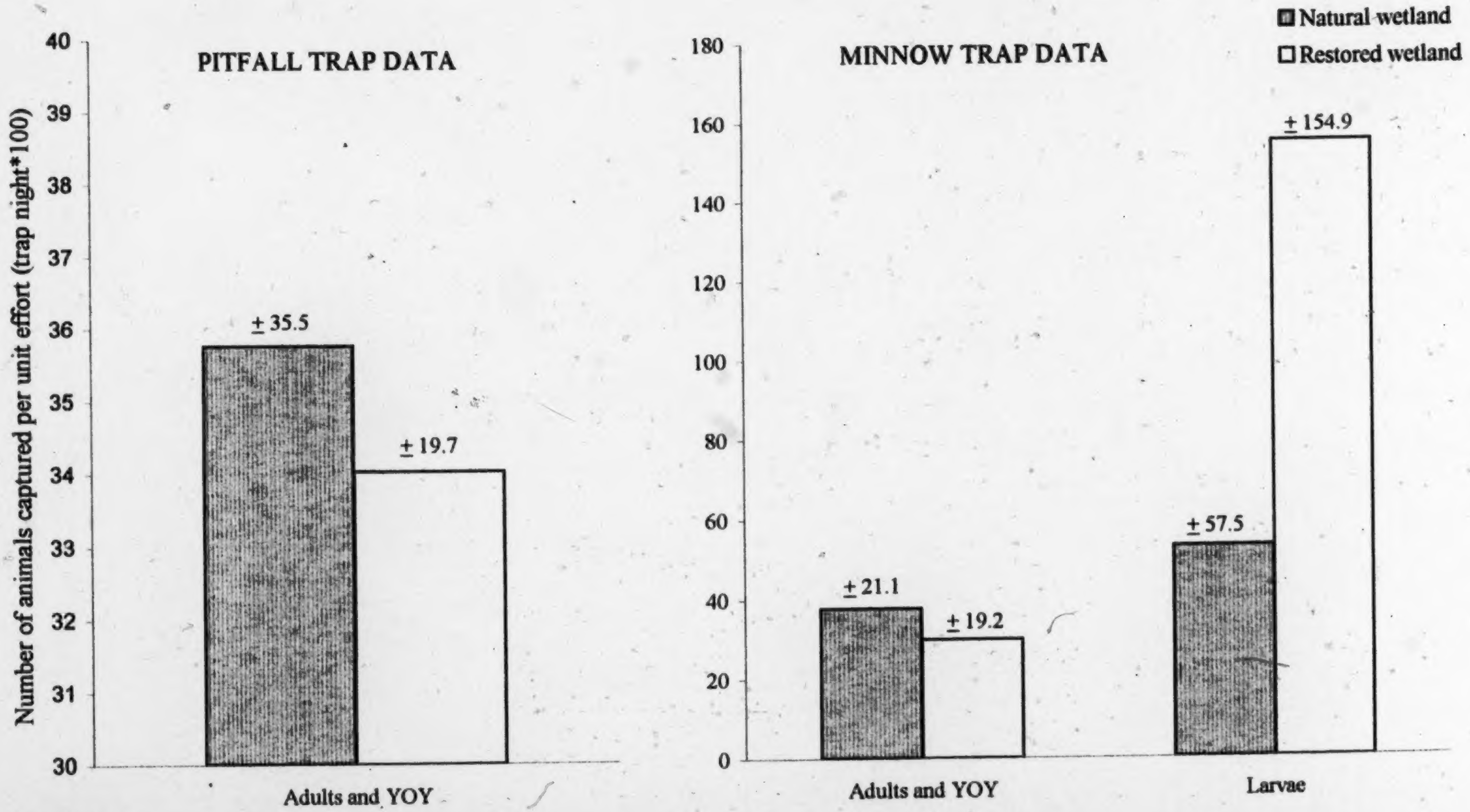
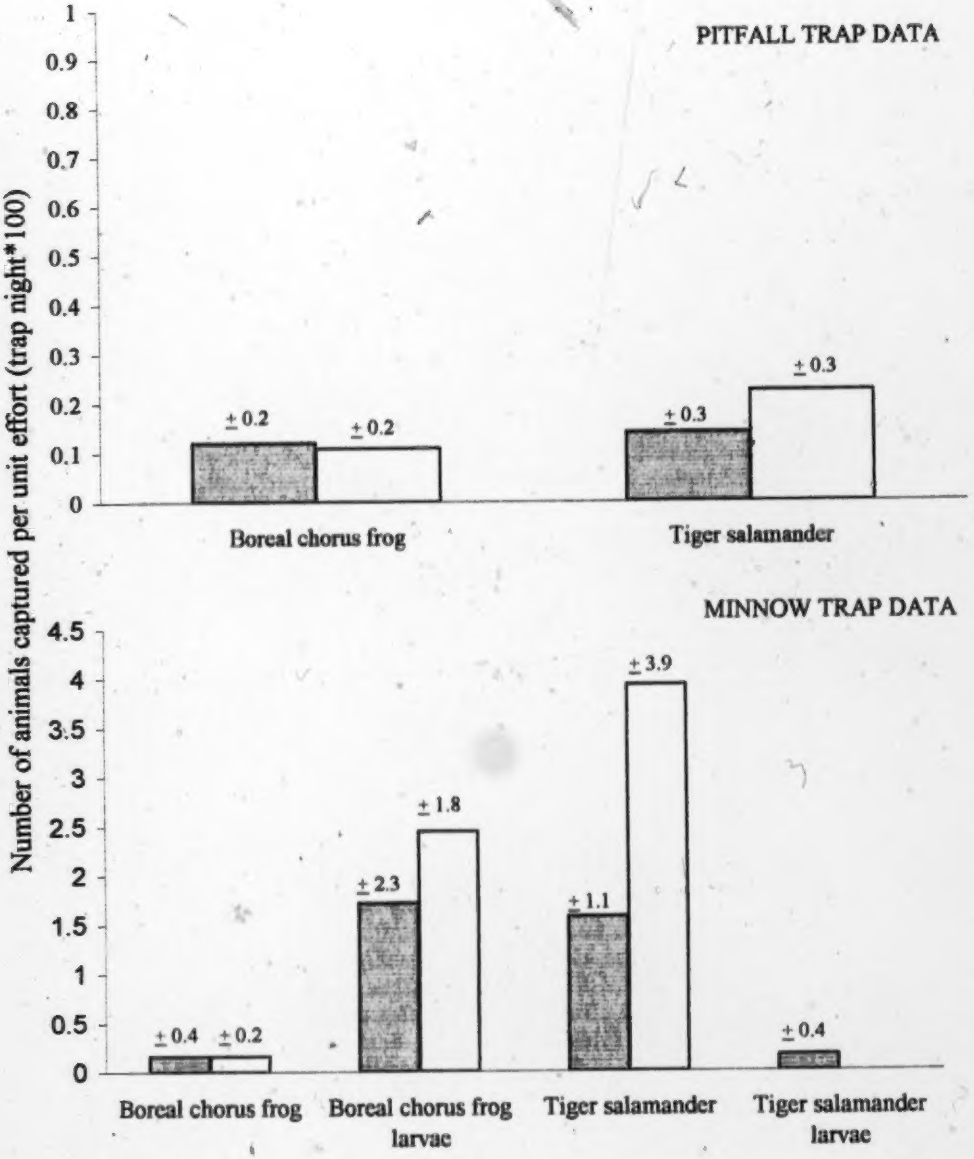


FIGURE 5.4a

Figure 5.4: A comparison of catch per unit effort rates in 6 natural and 6 restored wetlands for adults and young-of-year and for larvae of (a) wood frogs and (b) boreal chorus frogs and tiger salamanders captured in minnow and pitfall traps near Foam Lake, Saskatchewan, Canada 2000. Numbers above columns represent 1 standard deviation. Comparisons were made using Wilcoxon signed rank tests and none were significantly different.



PITFALL TRAP DATA
Number of animals captured per unit effort (trap night*100)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
± 0.2
± 0.2
± 0.3
± 0.3
Boreal chorus frog
Tiger salamander
MINNOW TRAP DATA
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
± 0.4
± 0.2
± 2.3
± 1.8
± 1.1
± 3.9
± 0.4
Boreal chorus frog
Boreal chorus frog larvae
Tiger salamander
Tiger salamander larvae

Figure 5.4b

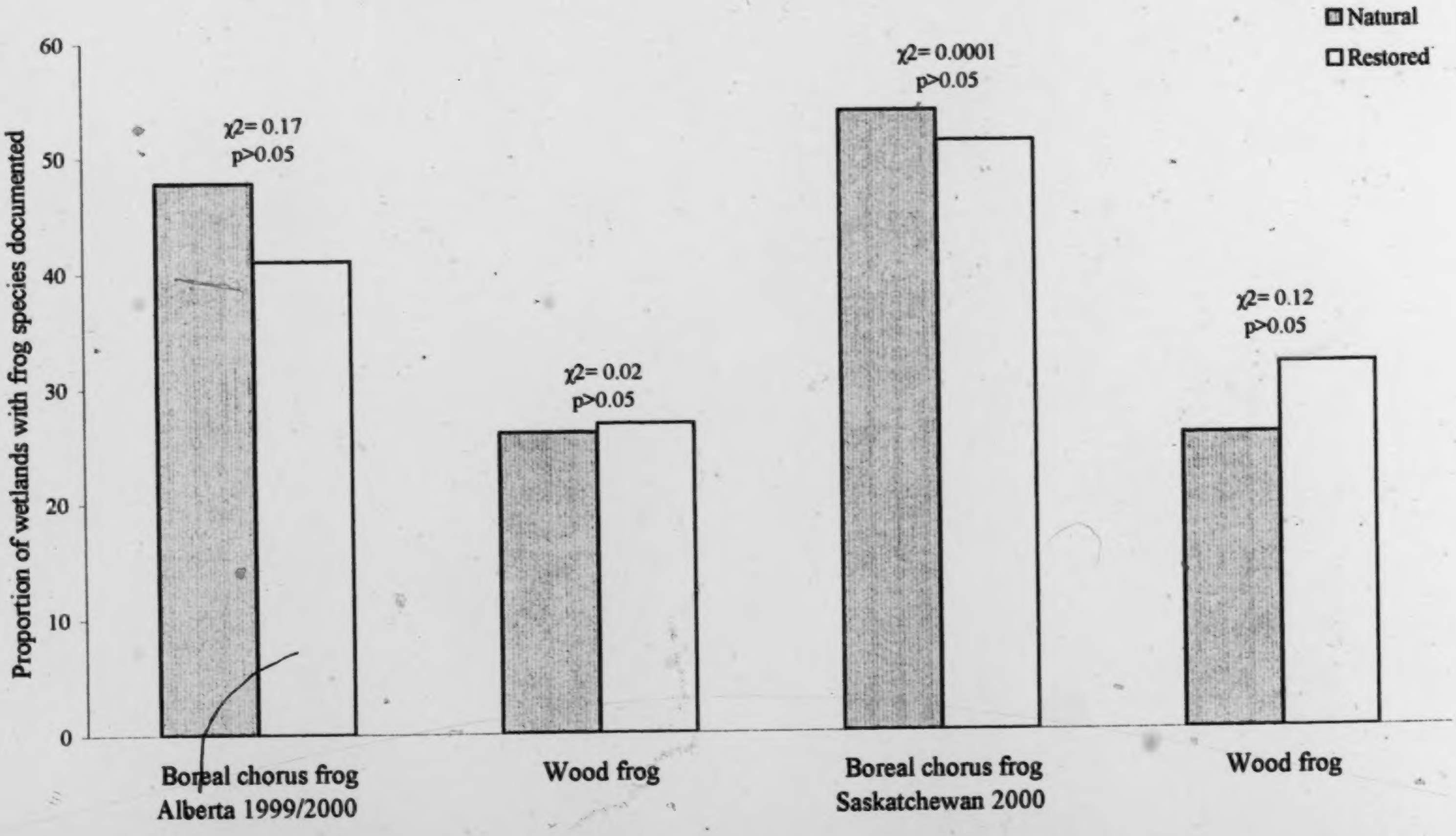


Figure 5.5: A comparison of boreal chorus and wood frog occurrence in 102 Alberta (56 restored) and 80 Saskatchewan (41 restored) prairie wetlands based on records from incidental observations and calls heard during bird surveys of the same wetlands. Comparisons of the proportion of natural versus restored wetlands with frogs documented were made using chi-squard tests; results are reported over columns. One degree of freedom is associated with each test. No comparisons were significantly different.

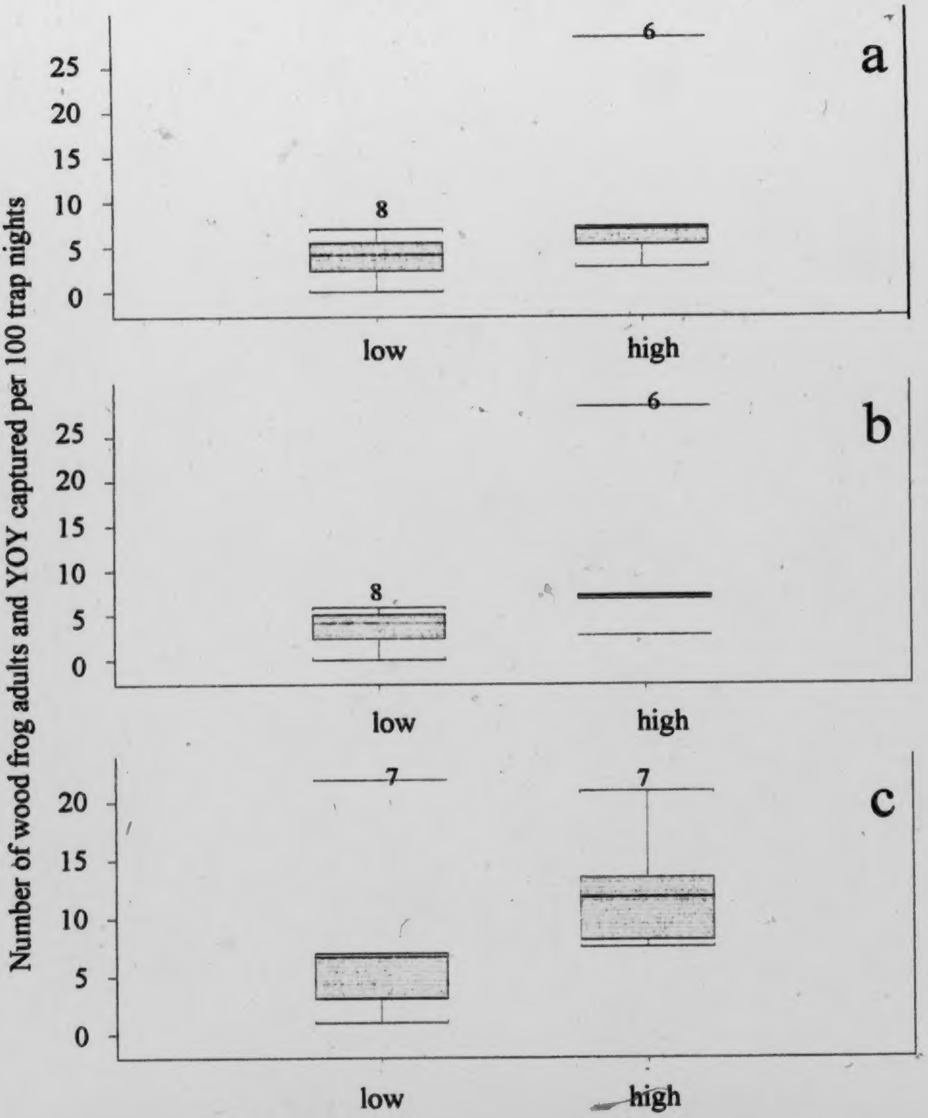


Figure 5.6: Box and whisker plot of wood frog pitfall (a & b) and minnow trap (c) capture rate by significant habitat characteristic categories (Wilcoxon signed rank, $p<0.10$) in wetlands near Camrose, Alberta 1999. a. mean estimated emergent band width (m), EMERG b. mean wetland depth (cm), DEPTH c. mean proportion of wetland habitat within a 500 m radius, WETLAND. Numbers above boxes = numbers of wetlands. Edges of box are 1st and 3rd quantiles, middle lines are medians, whiskers represent minimums and maximums, unconnected horizontal bars represent outliers.

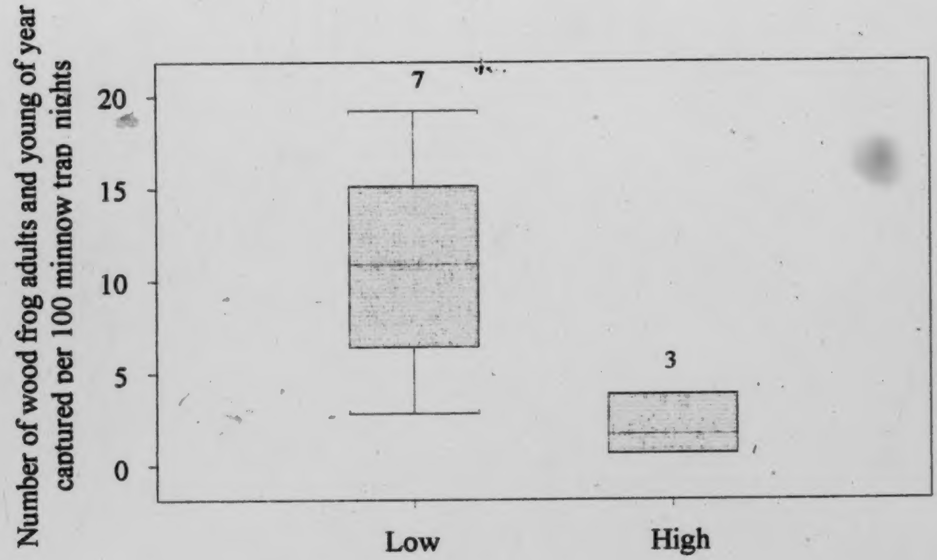


Figure 5.7: Box and whisker plot of wood frog pitfall capture rate by mean wetland area (AREA) categories (Wilcoxon signed rank, $p<0.10$) near Camrose, Alberta, Canada in 2000. Numbers above boxes = number of wetlands. Edges of box are 1st and 3rd quantiles, middle lines are medians, whiskers represent minimums and maximums, unconnected horizontal bars represent outliers.

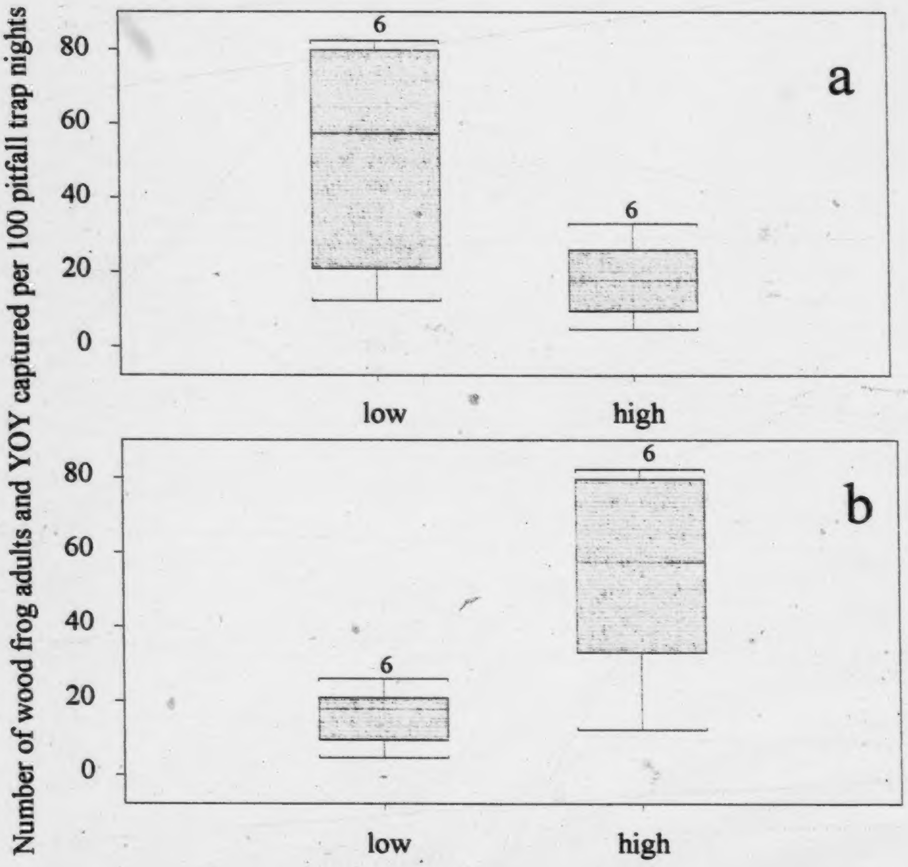


Figure 5.8: Box and whisker plot of wood frog pitfall capture rate by significant habitat characteristic categories (Wilcoxon signed rank, $p<0.10$) north of Foam Lake, Saskatchewan in 2000. a. mean estimated upland plant height (cm), UPHT b. mean proportion of woodland area in the surrounding 500 m radius, WOOD c. pH. Numbers above boxes = number of wetlands. Edges of box are 1st and 3rd quantiles, middle lines are medians, whiskers represent minimums and maximums, unconnected horizontal bars represent outliers.

CHAPTER 6

SUMMARY AND MANAGEMENT RECOMMENDATIONS

In the preceding four chapters, I have examined the similarity of restored and natural wetlands to assess the success of wetland restoration in the Prairie Pothole Region (PPR) of Canada. Here I will discuss my major findings and management recommendations. These findings are summarized in Table 6.1.

The first step in the recovery of wildlife at restored wetlands is the establishment of a wetland plant community. By using a non-overlapping system of quadrats, I compared plant species richness, diversity and composition in restored and natural wetlands (Chapter 2). Plant communities of Class III and IV wetlands (Stewart and Kantrud 1971) were similar in restored and natural wetlands in 30 wetlands in Alberta and Saskatchewan. Unlike earlier studies in the southern PPR (Galatowitsch and van der Valk 1996a, 1996b), I observed diagnostic representatives of all plant guilds in restored wetlands in proportions similar to those in natural wetlands. These findings from 30 intensively surveyed wetlands were supported by observations in 152 (82 restored) additional wetlands in both provinces, where representative species of all life history guilds were also observed in comparable proportions in restored and natural wetlands.

The similarity of plant communities in restored and natural wetlands suggested that active re-planting of restored wetlands is not necessary. Aggressive weeds such as Canada thistle (*Cirsium arvense*) and canary reed grass (*Phalaris arundincaea*) were present in both wetland types and should be managed immediately and intensively, as they preclude the establishment of other species. Similarly, restored wetlands may support woody vegetation (*Salix* spp., *Populus* spp.) and managers will need to decide if woody vegetation is beneficial (e.g. providing nesting habitat for birds) or detrimental (e.g. providing perches for avian predators). Based on earlier studies (Galatowitsch and van der Valk 1994), managers must ensure that hydrology is maintained (i.e. the basin remains flooded) by inspecting physical works regularly (i.e. ditch plug is still functioning). Similarly, continued monitoring of plant communities is necessary to confirm success of wetland restoration and the management of invasive species.

The impetus for wetland restoration is based on the goals of the North American Waterfowl Management Plan (NAWMP 1986) and Ducks Unlimited Canada (DUC, Gray et al. 1999) to improve habitat for waterfowl and other wildlife. This study was designed to address these goals and assess restored wetlands as wetland-dependent bird habitat. As well, Galatowitsch et al. (1999) and Croonquist and Brooks (1991) found that birds were the most useful taxa for monitoring changes in wetlands related to wetland recovery and habitat disturbance. Therefore, I compared the species richness, diversity and composition of avian assemblages in 97 restored and 85 natural wetlands in Alberta and Saskatchewan by conducting point counts (Chapter 3 and 4).

In Alberta, local habitat features and landscape setting of restored wetlands were similar to natural wetlands in the area. It follows that with comparable habitat, bird assemblages were not significantly different between the two wetland types. Saskatchewan restored wetlands did not have habitat characteristics that were equivalent to natural wetlands (e.g. shallower basins, further from woodland patches). As a result of the differences in local and landscape attributes, I observed decreased species richness and diversity in Saskatchewan restored wetlands, and different upland bird assemblages in restored and natural wetlands. However, unlike earlier studies (e.g. Delphey and

Dinsmore 1993), bird species that nest in wet meadow and low prairie vegetation zones were present in restored wetlands, and wetland-dependent bird assemblages were comparable in restored and natural in both provinces.

Bird species vary greatly in their food and habitat resource needs, and managers should restore wetlands in a variety of sizes and classes to best preserve and enhance the greatest diversity of species. To ensure a mosaic of wetland complexes, future research should compare current wetland distribution to historical patterns to prevent under-representation of wetland classes and sizes.

The importance of local and landscape factors in shaping bird assemblages was emphasized by examining the species-habitat relationships in restored and natural wetlands. In Alberta, the variation in bird assemblages on wetlands was best attributed to differences in wetland depth, wetland shape, vegetative cover and surrounding wetland area. Whereas, Saskatchewan bird species composition was related to wetland depth, distance to nearest woodland and road, and the proportion of shallow marsh vegetation on a given wetland.

Future research should investigate the breeding success of birds nesting in restored wetlands as compared to natural wetlands. In addition, continued monitoring, using point counts methods as I have, will confirm the success of restored wetlands as avian habitat documented here. Further investigation and monitoring of restored wetlands in Saskatchewan is necessary to ensure that differences in habitat characteristics (e.g. wetland depth) do not preclude their use by wetland-dependent bird species over time.

Amphibian species occurrence and abundance, in general, have been poorly documented on the prairies, and their use of restored wetlands is primarily anecdotal.

The life cycle of amphibians is dramatically different from those of birds. As larvae, amphibians are essentially immobile and cannot move from a wetland if conditions become adverse, and as terrestrial adults, their mean dispersal distance is comparatively short (<300 m, Gibbs 2000). Therefore, amphibian use of restored wetlands provides additional information of their success as functioning ecosystems. Chapter 5 was designed to address the information gap and to assess restored wetlands as amphibian habitat using a combination of trapping techniques and observational records.

Restored wetlands in Alberta and Saskatchewan provide comparable breeding habitat for wood frog (*Rana sylvatica*) and boreal chorus frogs (*Pseudacris maculata*). I observed slightly larger wood frogs in restored wetlands and future research should compare food resources and invertebrate predator communities of restored and natural wetlands to address the potential causes and ramifications of these differences in body sizes. Tiger salamander (*Ambystoma tigrinim*) adults were captured in similar abundance in restored wetlands in Alberta 1999 and Saskatchewan 2000, but unlike earlier studies (Galatowitsch and van der Valk 1994, Lannoo et al. 1994), I did not document breeding (via captured larvae) in restored wetlands in either year or province.

Leopard frogs (*Rana pipiens*) and Canadian toads (*Bufo hemiophrys*) were not encountered in any surveyed wetlands in either year or province of study. Wetland loss has played a role in the decline of many amphibian species, and future research should include an investigation of the wetland habitats that are required by these species for over-wintering and/or breeding and the potential of restoring appropriate wetland classes. Managers in Saskatchewan should take note of my findings and perhaps re-assess the status of these species locally.

Managers need to take into account both local (e.g. water chemistry, wetland vegetation) and landscape characteristics (e.g. inter-wetland distance) of wetlands when planning restorations for amphibians. Ideally, future monitoring of amphibians in restored wetlands would involve a combination of trapping techniques (e.g. minnow traps, seining, funnel traps, pitfall traps and/or call surveys, Heyer et al. 1994), as one method does not accurately document all species.

Class III and IV restored wetlands in the PPR of Canada possess similar plant communities and provide comparable habitat for wetland-dependent birds and amphibians. Restoration should continue to play an important role in wetland conservation strategies in Canada. To the extent that time and money permit, regular monitoring of these sites should continue. Minimally, any visit to monitor physical works should include a brief vegetation survey and summary of birds, amphibians and other wildlife present. More detailed surveys, as those presented here, should be conducted when possible to confirm the success of restored wetlands, and to document potential changes over time.

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Table 6.1: Summary of major findings and management recommendations for surveys of plant, bird and amphibian assemblages in restored and natural wetlands near Camrose, Alberta (AB) and Foam Lake, Saskatchewan (SK) in 1999 and 2000. ✓=success.

TAXON	SURVEY METHOD	PROV		MAJOR FINDINGS	RECOMMENDATIONS
Plants	Non-overlapping system of quadrats	AB SK	✓ ✓	Comparable species richness and composition in restored and natural wetlands Species of all life-history guilds present in restored wetlands	Monitor and control weeds in restored and natural wetlands Monitor development of woody vegetation in restored wetlands Active re-planting is not necessary
Birds	Modified point count	AB	✓ ✓	Comparable habitat in restored and natural wetlands Similar species richness, diversity and composition	Future research to assess the success of breeding in restored wetlands Comparison of current wetland distribution to historical patterns Restore wetlands in variety of sizes and classes Local and landscape features are important to planning restorations for birds
		SK	 ✓ ✓ 	Restored wetlands were shallower, further from woodland habitat, closer to roads with less complex shorelines than natural wetlands Representatives of all nesting guilds Reduced species richness and diversity in restored than natural wetlands Similar wetland-dependant bird species composition in restored and natural wetlands Upland bird species composition in restored wetlands =grassland and in natural wetlands = woodland	Further investigation into habitat differences in restored and natural wetlands in Saskatchewan
Amphibians	Trapping and observational records	All sites	 ✓	Absence of tiger salamander breeding in restored wetlands Comparable casual observations of wood and boreal chorus frog in wetlands of both types	Continued monitoring with a variety of techniques (e.g. trapping and call surveys) Distance between wetlands should be >300 m
		AB 99	✓ 	Comparable abundance in all 3 species in restored and natural wetlands Larger bodied wood frogs in restored wetlands	Local and landscape features are important to planning restorations for amphibians Further investigation into absence of salamander breeding and differences in wood frog body sizes
		AB 00	✓ 	Comparable wood frog abundance in wetland types Fewer boreal chorus frogs in natural wetlands Fewer tiger salamanders in restored wetlands Larger bodied wood frogs in restored wetlands	
		SK 00	✓	Comparable abundance for all 3 species in restored and natural wetlands	

Appendix 1: A summary of the restored and natural wetlands surveyed for amphibians and vegetation in 1999 and 2000 in the Aspen Parkland of Alberta and Saskatchewan.

Project	Pond ID	Wetland Size (Ha)	Year Surveyed	Year Restored	Northing	Easting	Zone
ALBERTA							
A&A Johnson	A	0.20	1999/2000	-	5873923	355237	12
Blue Sky	A	0.40	1999/2000	-	5873814	365355	12
Blue Sky	B	0.08	1999/2000	-	5874252	364932	12
Hagstrom	A	0.04	1999	-	5884868	351614	12
Hagstrom	B	0.20	1999	-	5884875	351741	12
Hagstrom	C	0.40	2000	-	5884968	351700	12
Lyseng	A	0.12	2000	-	5890761	369859	12
Matson	28	0.08	1999	-	5893394	369825	12
Mittelstadt	A	0.24	1999	-	5894131	357876	12
A&A Johnson	11	0.16	1999	1994	5873717	355078	12
A&A Johnson	6	0.24	2000	1994	5873500	355497	12
Beck	1	0.77	1999/2000	1993	5880270	367112	12
Coykendall	55	0.16	1999/2000	1994	5893882	372248	12
Maruschak	12	0.24	1999/2000	1995	5894007	358701	12
Maruschak	24	0.04	1999	1995	5893452	358539	12
Mittelstadt	13	0.45	1999	1993	5893994	357791	12
Mittelstadt	16	0.04	1999	1993	5893955	357924	12
Mittelstadt	2	0.12	2000	1993	5893635	357435	12
SASKATCHEWAN							
Belitski	A	0.20	2000	-	5746221	637231	13
Fullowka	A	0.08	2000	-	5748856	633799	13
Hauers	E	0.20	2000	-	5750732	630882	13
Koehl	A	0.40	2000	-	5756015	624116	13
Louie Brezinski	E	0.40	2000	-	5751741	632340	13
Shushetski	A	0.08	2000	-	5744575	653038	13
Belitski	8	0.18	2000	1996	5746039	637556	13
Brezinski	5	0.16	2000	1994	5742511	651841	13
Gulka	1	0.45	2000	1996	5745091	656014	13
Loshka	1	0.61	2000	1996	5743137	651596	13
Louie Brezinski	3	0.12	2000	1997	5751802	633070	13
Shewchuk	1	0.20	2000	1992	5745063	637562	13

Appendix 2: Restored and natural wetlands surveyed for birds within 100 km of Camrose, Alberta in 1999 and 2000. Wetlands were classified as seasonal (III) or semi-permanent (IV) according to Stewart and Kantrud (1971). Year of restoration indicates the year ditch plugs were constructed (often in the fall of that year). DUC project location refers to the legal land location for the project on each specified wetland was found. Wetland location lists the UTM coordinates for each surveyed wetland. Code indicates the abbreviation used in tables and figures. Wetlands marked with an asterisk (*) were surveyed in both years.

							DUC project location					Wetland location		
CODE	Project	Wetland No.		Wetland class	Size (m^2)	Year of restoration	1/4	Sec.	TWP	RGE	W	Northing	Easting	Zone
AAJO11	A&A Johnson	11		IV	1619.4	1995	SE	29	46	22	4	5873717	355078	12
AAJOH6	A&A Johnson	6		III	2429.2	1995	SE	29	46	22	4	5873500	355497	12
AAJOHA	A&A Johnson	A	*	IV	2024.3	natural	SE	29	46	22	4	5873923	355237	12
AAJOHB	A&A Johnson	B		IV	6882.6	natural	SE	29	46	22	4	5873669	355550	12
ANDREA	Andrews	A	*	IV	2834.0	natural	NE	14	42	21	4	5832080	370648	12
ANDREB	Andrews	B		IV	2429.2	natural	NE	14	42	21	4	5831953	370660	12
ANDREC	Andrews	C		III	1214.6	natural	NE	14	42	21	4	5832070	370329	12
BAINEB	Baines	B	*	III	2024.3	natural	SW	30	38	21	4	5795614	363488	12
BAND10	B&E	10		III	202.4	1993	NW	16	35	25	4	5764624	327078	12
BANDE4	B&E	4		IV	809.7	1993	NW	16	35	25	4	5765052	362884	12
BANDE6	B&E	6		IV	2834.0	1993	NW	16	35	25	4	5765144	326773	12
BANDE9	B&E	9		IV	2429.2	1993	NW	16	35	25	4	5765280	327170	12
BANDEA	B&E	A	*	IV	3643.7	natural	NW	16	35	25	4	5764677	326660	12
BECK01	Beck-22	1	*	IV	7692.3	1993	NE	15	47	21	4	5880270	367112	12
BLSKYA	Blue Sky	A	*	IV	2834.0	natural	NE	29	46	21	4	5873814	365355	12
BLSKYB	Blue Sky	B	*	III	404.9	natural	NE	29	46	21	4	5874252	364932	12
BLSKYC	Blue Sky	C		III	1619.4	natural	NE	29	46	21	4	5873765	365210	12
BOYD02	Boyden	2	*	III	404.9	1994	SE	11	36	23	4	5771777	350563	12
BOYD06	Boyden	6	*	III	404.9	1994	SE	11	36	23	4	5771231	350832	12
CASS01	Cassidy	1		IV	1619.4	1992	NE	16	37	20	4	5783002	376860	12
CASS04	Cassidy	4		IV	1619.4	1992	NE	16	37	20	4	5782880	377218	12
CASS06	Cassidy	6	*	IV	6477.8	1992	NE	16	37	20	4	5783161	377249	12
CHUR28	Churchill	28	*	III	404.9	1995	SE	12	49	21	4	5897790	370837	12

							DUC project location					Wetland location		
CODE	Project	Wetland No.		Wetland class	Size (m^2)	Year of restoration	1/4	Sec.	TWP	RGE	W	Northing	Easting	Zone
CHURCA	Churchill	A		III	404.9	natural	SE	12	49	21	4	5897794	370700	12
COYK35	Coykendall	35		III	1214.6	1994	SE	31	48	20	4	5894164	372307	12
COYK55	Coykendall	55	*	III	1619.4	1994	SE	31	48	20	4	5893882	372248	12
DOUBAB	Double A	B	*	III	404.9	natural	SE	27	48	11	4	5890811	464954	12
DOUBAC	Double A	C	*	IV	2429.2	natural	SE	27	48	11	4	5890807	465098	12
FEIL03	Feil	3		III	809.7	1995	SW	36	35	22	4	5767669	360967	12
FEIL04	Feil	4	*	IV	4048.6	1995	SW	36	35	22	4	5767669	361118	12
FEIL05	Feil	5		IV	3238.9	1995	SW	36	35	22	4	5767615	361230	12
FEIL0B	Feil	B	*	IV	2429.2	natural	SW	36	35	22	4	5767656	361404	12
FEIL0D	Feil	D		III	3238.9	natural	SW	36	35	22	4	5767730	361501	12
GREEN1	Greenwood	1		III	404.9	1995	NW	36	35	22	4	5768617	360939	12
HAGE02	Haskell/George	2	*	III	2024.3	1994	SE	3	37	23	4	5779674	349151	12
HAGE03	Haskell/George	3		III	809.7	1994	SE	3	37	23	4	5779780	349037	12
HAGE04	Haskell/George	4		III	809.7	1994	SE	3	37	23	4	5780024	349090	12
HAGSTA	Hagstrom	A	*	III	404.9	natural	SW	31	47	22	4	5884868	351614	12
HAGSTB	Hagstrom	B	*	IV	809.7	natural	SW	31	47	22	4	5884875	351741	12
HAGSTC	Hagstrom	C		IV	2834.0	natural	SW	31	47	22	4	5884968	351700	12
HAGSTD	Hagstrom	D		III	809.7	natural	SW	31	47	22	4	5884699	351689	12
HANS12	Hanson	12		III	1619.4	1994	NE	17	48	11	4	5888260	461533	12
HAWTHA	Hawthorne	A		III	1214.6	natural	NW	24	38	24	4	5794922	342409	12
HAWTHB	Hawthorne	B		III	809.7	natural	NW	24	38	24	4	5794958	342446	12
HAWTHC	Hawthorne	C	*	III	3238.9	natural	NW	24	38	24	4	5795137	342441	12
KALL02	Kallal	2		III	2429.2	1995	N	25	50	18	4	5912206	399903	12
KLEING	Klein	G		IV	2834.0	natural	SW	14	28	12	4	5887444	456290	12
LOCKEG	Locke	G		IV	4858.3	natural	NW	19	38	21	4	5794870	363578	12
LOCKEH	Locke	H		III	1214.6	natural	NW	19	38	21	4	5794727	363584	12
LOCKEI	Locke	I	*	IV	2429.2	natural	NW	19	38	21	4	5794490	363576	12
LOVE12	Loveseth 1	2		IV	1214.6	1994	SW	23	48	11	4	5889307	466116	12

							DUC project location					Wetland location		
CODE	Project	Wetland No.		Wetland class	Size (m^2)	Year of restoration	1/4	Sec.	TWP	RGE	W	Northing	Easting	Zone
LOVE2A	Loveseth 2	A		III	1619.4	natural	SE	26	48	11	4	5890864	466787	12
LOVE2B	Loveseth 2	B	*	III	1214.6	natural	SE	26	48	11	4	5890889	466846	12
LOVE2C	Loveseth 2	C		III	1214.6	natural	SE	26	48	11	4	5890397	466957	12
LYSE44	Lyseng	44		IV	404.9	1995	SW	24	48	21	4	5890777	370103	12
LYSE46	Lyseng	46		III	404.9	1995	SW	24	48	21	4	5890824	369813	12
LYSE47	Lyseng	47	*	III	809.7	1995	SW	24	48	21	4	5890728	369791	12
LYSENA	Lyseng	A	*	IV	1214.6	natural	SW	24	48	21	4	5890761	369859	12
LYSENB	Lyseng	B	*	III	1214.6	natural	SW	24	48	21	4	5890661	370174	12
MARU12	Maruschak	12	*	IV	2429.2	1995	NW	26	48	22	4	5894007	358701	12
MARU24	Maruschak	24	*	IV	404.9	1995	NW	26	48	22	4	5893452	358539	12
MARUS8	Maruschak	8		III	1619.4	1995	NW	26	48	22	4	5894022	358350	12
MATS28	Matson	28		III	809.7	natural	NW	25	48	21	4	5893394	369825	12
MCLEA2	McLean	2	*	IV	404.9	1995	NW	20	48	11	4	5890198	460968	12
MCLEA9	McLean	9	*	III	3643.7	1995	NW	20	48	11	4	5889823	461114	12
MITT13	Mittelstadt	13		III	4453.5	1993	NE	27	48	22	4	5893994	357791	12
MITT16	Mittelstadt	16		III	404.9	1993	NE	27	48	22	4	5893955	357924	12
MITTE2	Mittelstadt	2	*	IV	1214.6	1993	NE	27	48	22	4	5893635	357435	12
MITTE6	Mittelstadt	6		IV	809.7	1993	NE	27	48	22	4	5893461	357387	12
MITTE8	Mittelstadt	8	*	IV	809.7	1993	NE	27	48	22	4	5893518	357625	12
MITTEA	Mittelstadt	A	*	III	2429.2	natural	NE	27	48	22	4	5894131	357876	12
PARFEA	Parfett	A	*	IV	404.9	natural	SW	27	46	22	4	5874087	357614	12
RA1205	Rauser 1&2	5	*	IV	1214.6	1996	S	6	48	10	4	5884041	469143	12
RA120A	Rauser 1&2	A		IV	5263.2	natural	S	6	48	10	4	5884033	470111	12
RA1212	Rauser 1&2	12	*	IV	1214.6	1996	S	6	48	10	4	5884234	469395	12
RA1214	Rauser 1&2	14		IV	809.7	1996	S	6	48	10	4	5884250	469500	12
RA1222	Rauser 1&2	22		IV	6477.8	1996	S	6	48	10	4	5884381	469730	12
RA1223	Rauser 1&2	23	*	IV	404.9	1996	S	6	48	10	4	5884447	469791	12
RA1229	Rauser 1&2	29	*	IV	809.7	1996	S	6	48	10	4	5884622	470074	12

							DUC project location					Wetland location		
CODE	Project	Wetland No.		Wetland class	Size (m^2)	Year of restoration	1/4	Sec.	TWP	RGE	W	Northing	Easting	Zone
RA1230	Rauser 1&2	30		IV	2024.3	1996	S	6	48	10	4	5884525	470239	12
RA1246	Rauser 1&2	46	*	IV	404.9	1996	S	6	48	10	4	5884308	469076	12
RA1249	Rauser 1&2	49		III	1214.6	1996	S	6	48	10	4	5884487	468929	12
RAUS4A	Rauser 4	A		IV	404.9	natural	NW	18	48	10	4	5888593	469365	12
RAUS4B	Rauser 4	B	*	IV	404.9	natural	NW	18	48	10	4	5888433	469039	12
RAUS4C	Rauser 4	C		III	404.9	natural	NW	18	48	10	4	5888384	469051	12
RAUS4D	Rauser 4	D		IV	404.9	natural	NW	18	48	10	4	5888396	469095	12
RAUS4F	Rauser 4	F	*	III	404.9	natural	NW	18	48	10	4	5888005	469212	12
RAUS4G	Rauser 4	G	*	III	1214.6	natural	NW	18	48	10	4	5888157	469416	12
RAUS4H	Rauser 4	H	*	IV	404.9	natural	NW	18	48	10	4	5888285	469432	12
RAUS4I	Rauser 4	I		III	404.9	natural	NW	18	48	10	4	5888040	469295	12
RAUS5A	Rauser 5	A	*	IV	1619.4	natural	SE	1	48	12	4	5883994	458815	12
SIEM02	Siemens	2		IV	1214.6	1995	SW	33	42	21	4	5835321	366506	12
SIEM03	Siemens	3		III	809.7	1995	NW	28	42	21	4	5835214	366539	12
SIEM07	Siemens	7		III	809.7	1995	SW	33	42	21	4	5836147	366638	12
SIEM09	Siemens	9		IV	2429.2	1995	NW	28	42	21	4	5832085	370648	12
SOREN1	Sorenson	1		IV	4048.6	1994	SW	10	48	12	4	5886590	453426	12
SOREN2	Sorenson	2		III	5263.2	1994	SW	10	48	12	4	5886481	453356	12
SORENA	Sorenson	A	*	IV	3643.7	natural	SW	10	48	12	4	5887032	453495	12
WIK003	Wik	3	*	IV	809.7	1996	SE	32	35	24	4	5768565	335915	12
WIK006	Wik	6		IV	5263.2	1996	SE	32	35	24	4	5768891	335767	12
WIK008	Wik	8	*	IV	1214.6	1996	SE	32	35	24	4	5768932	335629	12
WIK00A	Wik	A	*	IV	6882.6	natural	SE	32	35	24	4	5768395	336215	12

Appendix 3: Restored (41) and natural (39) wetlands surveyed for birds within 150 km of Foam Lake, Saskatchewan in 2000. Wetlands were classified as seasonal (III) or semi-permanent (IV) according to Stewart and Kantrud (1971). Year of restoration indicates the year ditch plugs were constructed (often in the fall of that year). DUC project refers to the legal land location for the project on which the specified wetland was found. Wetland location lists the UTM coordinates for each surveyed wetland. Code indicates the abbreviation used in tables and figures.

						DUC project location					Wetland location		
CODE	**Project**	**Wetland**	**Wetland class**	**Size (m2)**	**Year of restoration**	**1/4**	**Sec.**	**TWP**	**RGE**	**W**	**Northing**	**Easting**	**Zone**
ADAM04	Adam	4	IV	3646.0	1997	NE	27	23	32	1	5655513	298380	14
ADAM06	Adam	6	IV	4456.0	1997	NE	27	23	32	1	5655559	298799	14
ADAM07	Adam	7	IV	2836.0	1997	NE	27	23	32	1	5655207	298355	14
ANDER2	Anderson Uplands	2	IV	8506.0	1997	SW	8	24	32	1	5659910	294356	14
ANDER3	Anderson Uplands	3	III	4051.0	1997	SW	8	24	32	1	5659719	294710	14
ANDERA	Anderson Uplands	A	III	4051.0	Natural	SW	8	24	32	1	5660443	294927	14
ANDERB	Anderson Uplands	B	IV	2431.0	Natural	NE	7	24	32	1	5660853	293855	14
BANK0B	Bankend	B	IV	4456.0	Natural	SW	8	29	13	2	5705265	582196	13
BANK0D	Bankend	D	IV	2836.0	Natural	SW	8	29	13	2	5705634	582189	13
BELI08	Belitski	8	IV	2836.0	1996	NE	24	33	8	2	5746039	637556	13
BELI0A	Belitski	A	IV	2836.0	Natural	NE	24	33	8	2	5746221	637231	13
BIGOR5	Bigoraj	5	IV	1216.0	1993	SE	21	33	7	2	5745741	641968	13
BIGOR8	Bigoraj	8	IV	2026.0	1993	SE	21	33	7	2	5745616	642289	13
BREZ02	Brezinski	2	IV	1621.0	1994	SE	9	33	6	2	5742724	652201	13
BREZ05	Brezinski	5	IV	1621.0	1994	SE	9	33	6	2	5742511	651841	13
FAYE01	Faye Uplands	1	IV	406.0	1992	NW	16	26	13	2	5675416	585620	13
FULL0A	Fullowka	A	IV	811.0	Natural	NE	34	33	8	2	5748856	633799	13
GULKA1	Gulka	1	IV	4456.0	1996	NE	16	33	6	2	5745091	656014	13
HAUERE	Hauers	E	IV	3241.0	Natural	NE	5	34	8	2	5750732	630882	13
HAUERF	Hauers	F	IV	2431.0	Natural	NE	5	34	8	2	5750679	630668	13
HAUERH	Hauers	H	IV	2026.0	Natural	SE	5	34	8	2	5750231	631093	13

						DUC project location					Wetland location		
CODE	Project	Wetland	Wetland class	Size (m2)	Year of restoration	1/4	Sec.	TWP	RGE	W	Northing	Easting	Zone
HAUERK	Hauers	K	IV	2836.0	Natural	SE	5	34	8	2	5750154	630974	13
KLUS0A	Klus	A	IV	1216.0	Natural	NE	36	24	9	2	5664927	630218	13
KLUS0D	Klus	D	IV	406.0	Natural	NE	36	24	9	2	5664367	630903	13
KLUS0F	Klus	F	IV	406.0	Natural	NE	36	24	9	2	5664791	630449	13
KLUS0H	Klus	H	IV	811.0	Natural	NE	36	24	9	2	5664660	630720	13
KOEHLA	Koehl	A	IV	7291.0	Natural	SE	27	34	9	2	5756015	624116	13
KOTUR3	Koturbash	3	IV	12151.0	1993	SE	18	33	7	2	5743549	639034	13
KOTURA	Koturbash	A	IV	406.0	Natural	SE	18	33	7	2	5743612	639294	13
KOWA02	Kowalchuk	2	IV	2026.0	1997	SW	10	25	2	2	5667211	626346	13
KOWA07	Kowalchuk	7	IV	811.0	1992	SW	10	25	2	2	5666782	626240	13
KOWA09	Kowalchuk	9	IV	811.0	1992	SW	10	25	2	2	5666715	626114	13
KOWA0A	Kowalchuk	A	IV	811.0	Natural	SW	10	25	2	2	5667322	626597	13
KOZE05	Kozey Uplands	7	IV	2836.0	1996	SE	10	25	9	2	5667476	627176	13
KOZE07	Kozey Uplands	5	IV	811.0	1996	NE	10	25	9	2	5667115	626949	13
KOZE0A	Kozey Uplands	A	IV	1621.0	Natural	SE	10	25	9	2	5666999	627392	13
KOZE12	Kozey Uplands	12	IV	1216.0	1996	SE	10	25	9	2	5667321	627191	13
LEND0C	Lendvoy Uplands	C	IV	1621.0	Natural	SE	9	27A	15	2	5682027	566275	13
LEND0D	Lendvoy Uplands	D	IV	2431.0	Natural	SE	9	27A	15	2	5682583	565834	13
LOSH01	Loshka	1	IV	6076.0	1996	NE	8	33	6	2	5743137	651596	13
LOUIE1	Louis (Brezinski)	1	III	7291.0	1997	SE	9	34	8	2	5751907	632191	13
LOUIE3	Louis (Brezinski)	3	IV	1216.0	1997	SW	10	34	8	2	5751802	633070	13
LOUIE4	Louis (Brezinski)	4	IV	2431.0	1997	SW	10	34	8	2	5751572	633148	13
LOUIE5	Louis (Brezinski)	5	III	406.0	1997	SW	10	34	8	2	5751439	633173	13
LOUIEA	Louis (Brezinski)	A	III	1621.0	Natural	SE	9	34	8	2	5751827	632444	13
LOUIEE	Louis (Brezinski)	E	IV	4051.0	Natural	SE	9	34	8	2	5751741	632340	13
NADAMA	Near Adam	A	IV	8101.0	Natural	NW	26	23	32	1	5655546	299644	14

CODE	Project	Wetland	Wetland class	Size (m2)	Year of restoration	DUC project location 1/4	Sec.	TWP	RGE	W	Wetland location Northing	Easting	Zone
NICH01	Nichol Uplands	1	IV	811.0	1992	NW	30	29	13	2	5711122	580513	13
NICH02	Nichol Uplands	2	III	1216.0	1992	NW	30	29	13	2	5711258	580448	13
ONOFRA	Onofreychuk	A	IV	1621.0	Natural	NW	31	24	32	1	5666922	293475	14
ONOFRB	Onofreychuk	B	IV	1621.0	Natural	NW	31	24	32	1	5667252	293031	14
PATR01	Patron Uplands	1	III	1216.0	1996	SE	4	25	7	2	5665368	625877	13
PATR02	Patron Uplands	2	IV	2026.0	1996	SE	4	25	7	2	5665190	625357	13
PATR03	Patron Uplands	3	IV	7291.0	1996	SE	4	25	7	2	5712007	577184	13
PATRIB	Patrick Uplands	B	IV	811.0	Natural	SW	35	29	14	2	5665030	625217	13
S48221	Shewchuk, M	1	IV	3241.0	1997	SE	7	30	15	2	5745063	637562	13
S48222	Shewchuk, M	2	IV	2431.0	1997	SE	7	30	15	2	5745077	652028	13
SAWCHA	Sawchuk Uplands	A	IV	811.0	Natural	SW	10	24	32	1	5714807	561907	13
SAWCHD	Sawchuk Uplands	D	IV	4051.0	Natural	SW	10	24	32	1	5715192	561815	13
SAWCHH	Sawchuk Uplands	H	IV	1216.0	Natural	SW	10	24	32	1	5659525	297780	14
SAYLY1	Saylyn	1	IV	2026.0	?	SE	15	27	32	1	5659611	297823	14
SCHIC1	Schick Uplands	1	IV	2431.0	1996	SW	6	24	7	2	5659725	297840	14
SCHIC2	Schick Uplands	2	IV	1621.0	1996	SW	6	24	7	2	5691074	297672	14
SCHIC3	Schick Uplands	3	IV	811.0	1996	SW	6	24	7	2	5655967	641224	13
SEIPOC	Seip Uplands	C	III	1216.0	Natural	SW	17	26	13	2	5655634	641472	13
SHEW01	Shewchuk	1	IV	6886.0	1992	SE	24	33	8	2	5655765	641121	13
SHEW05	Shewchuk	5	IV	7291.0	1992	SE	24	33	8	2	5674841	584298	13
SHUSHA	Shushetski	A	IV	811.0	Natural	NW	15	33	6	2	5744575	653038	13
SMITHB	Smith Uplands	B	IV	811.0	Natural	SE	15	25	9	2	5668386	627084	13
SMITHC	Smith Uplands	C	IV	406.0	Natural	SE	15	25	9	2	5669003	626813	13
SMITHD	Smith Uplands	D	IV	7696.0	Natural	SE	15	25	9	2	5668944	626985	13
SMITHF	Smith Uplands	F	IV	203.5	Natural	SE	15	25	9	2	5668714	627272	13
START1	Start Uplands	1	IV	1216.0	1992	SE	24	27	14	2	5688875	580214	13

						DUC project location					Wetland location		
CODE	**Project**	**Wetland**	**Wetland class**	**Size (m2)**	**Year of restoration**	**1/4**	**Sec.**	**TWP**	**RGE**	**W**	**Northing**	**Easting**	**Zone**
START2	Start Uplands	2	IV	1621.0	1992	SE	24	27	14	2	5688953	580170	13
STEINA	Stein	A	III	406.0	Natural	SW	15	34	8	2	5753650	633049	13
STEINC	Stein	C	IV	2431.0	Natural	SW	15	34	8	2	5753533	633270	13
TEMP01	Temple	1	IV	811.0	1992	NE	21	23	9	2	5651705,	626165	13
TEMP0A	Temple	A	IV	1621.0	Natural	NE	21	23	9	2	5651115	626197	13
WEHR02	Wehrer	2	IV	3241.0	1997	NW	14	23	32	1	5652364	299078	14
WEHR0A	Wehrer	A	IV	2026.0	Natural	NW	14	23	32	1	5651865	299110	14

Appendix 4: Summary of amphibian trapping data {pitfall and minnow traps combined (pitfall alone for adults and YOY)} for natural and restored wetlands near Camrose, Alberta for May 24 until August 04, 1999. YOY = young-of-year, PT = pitfall trap, MT = minnow trap

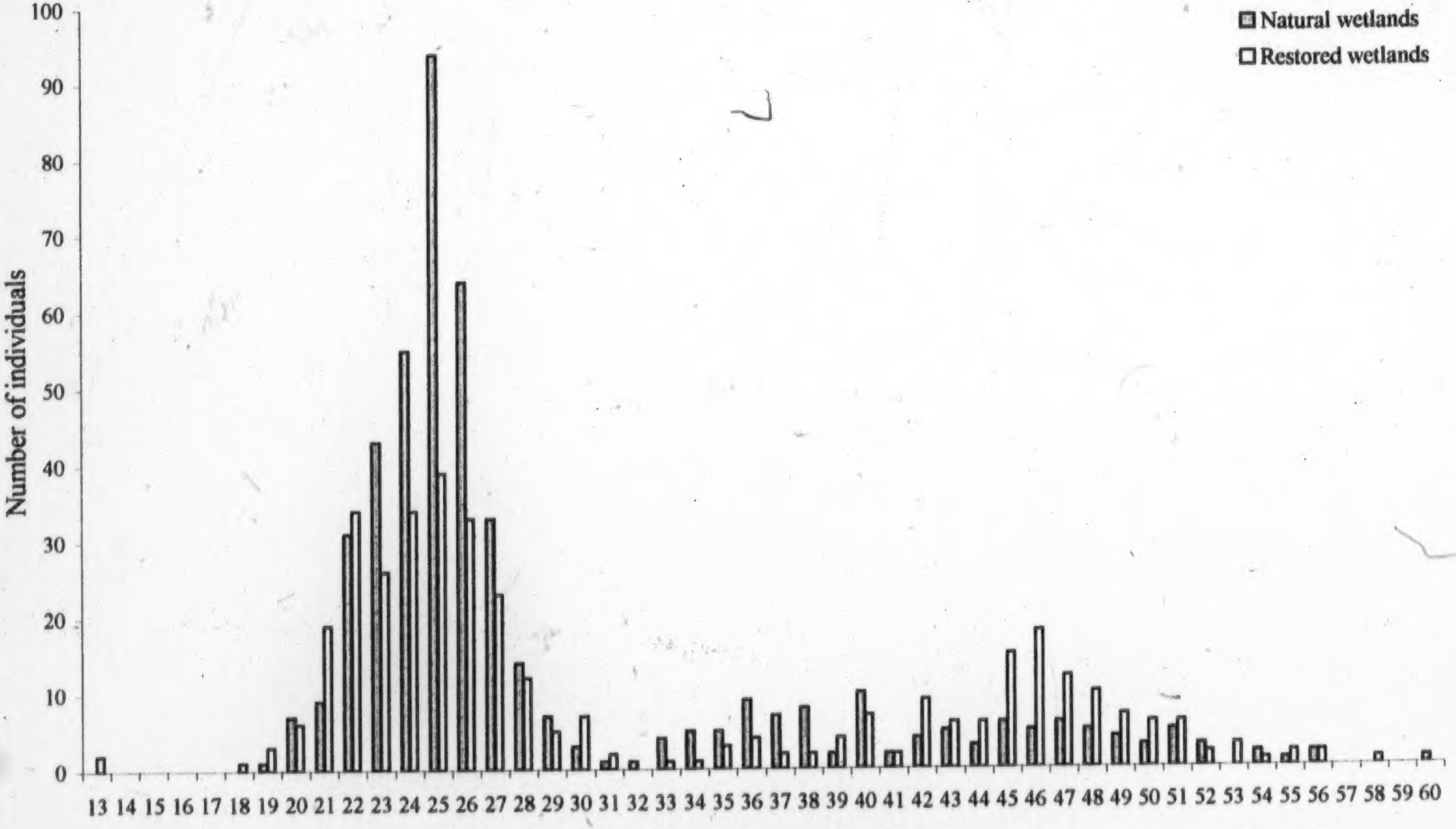
			Wood frogs			Boreal chorus frogs			Tiger salamanders			
Project Name	Type	Status	adults	YOY	larvae	adults	YOY	larvae	adults	larvae	No. of PT nights	No. of MT nights
A&A Johnson A	IV	natural	14 (2)	20 (19)	0	1 (1)	1 (1)	0	6 (0)	3	772	195
Blue Sky A	IV	natural	20 (17)	208 (197)	242	13 (13)	4 (4)	0	7 (2)	10	756	201
Blue Sky B	III	natural	7 (3)	17 (15)	42	5 (5)	1 (1)	0	0 (0)	0	792	198
Hagstrom A	III	natural	15 (4)	59 (43)	46	4 (4)	0 (0)	6	1 (1)	0	804	201
Hagstrom B	IV	natural	29 (15)	53 (41)	46	2 (2)	0 (0)	2	11 (1)	0	777	201
Matson	III	natural	8 (0)	0 (0)	0	0 (0)	0 (0)	1	1 (1)	0	524	117
Mittelstadt A	III	natural	32 (10)	15 (13)	0	2 (2)	0 (0)	0	0 (0)	0	540	204
		Subtotal	*125 (51)*	*372 (328)*	*376*	*27 (27)*	*6 (6)*	*9*	*26 (5)*	*13*	4965	1317
A&A Johnson 11	IV	restored	10 (3)	38 (35)	25	7 (7)	4 (4)	6	6 (0)	0	733	195
Beck-22	IV	restored	5 (4)	50 (49)	71	6 (6)	1 (1)	0	5 (2)	0	784	201
Coykendall 55	III	restored	60 (20)	24 (20)	229	1 (1)	0 (0)	0	1 (0)	0	804	201
Maruschak 12	IV	restored	18 (6)	20 (16)	0	5 (5)	0 (0)	15	0 (0)	0	565	198
Maruschak 24	IV	restored	18 (11)	80 (45)	321	1 (1)	6 (6)	41	0 (0)	0	785	201
Mittelstadt 13	III	restored	29 (13)	39 (37)	139	7 (7)	1 (1)	2	0 (0)	0	719	201
Mittelstadt 16	III	restored	18 (5)	9 (7)	12	2 (2)	0 (0)	39	0 (0)	0	490	201
		Subtotal	*158 (62)*	*260 (209)*	*797*	*29 (29)*	*12 (12)*	*103*	*12 (2)*	*0*	4880	1398
TOTAL (Pitfall)			283 (113)	632 (537)	1173	56 (56)	18 (18)	112	38 (7)	13	4965	1317

Appendix 5: Summary of amphibian trapping data {pitfall and minnow traps combined (pitfall alonefor adults and YOY)} for natural and restored wetlands near Camrose, Alberta for May 17 until July 29, 2000. Wetlands surveyed in both years are marked with an asterisk. YOY = young-of-year, PT = pitfall trap, MT = minnow trap.

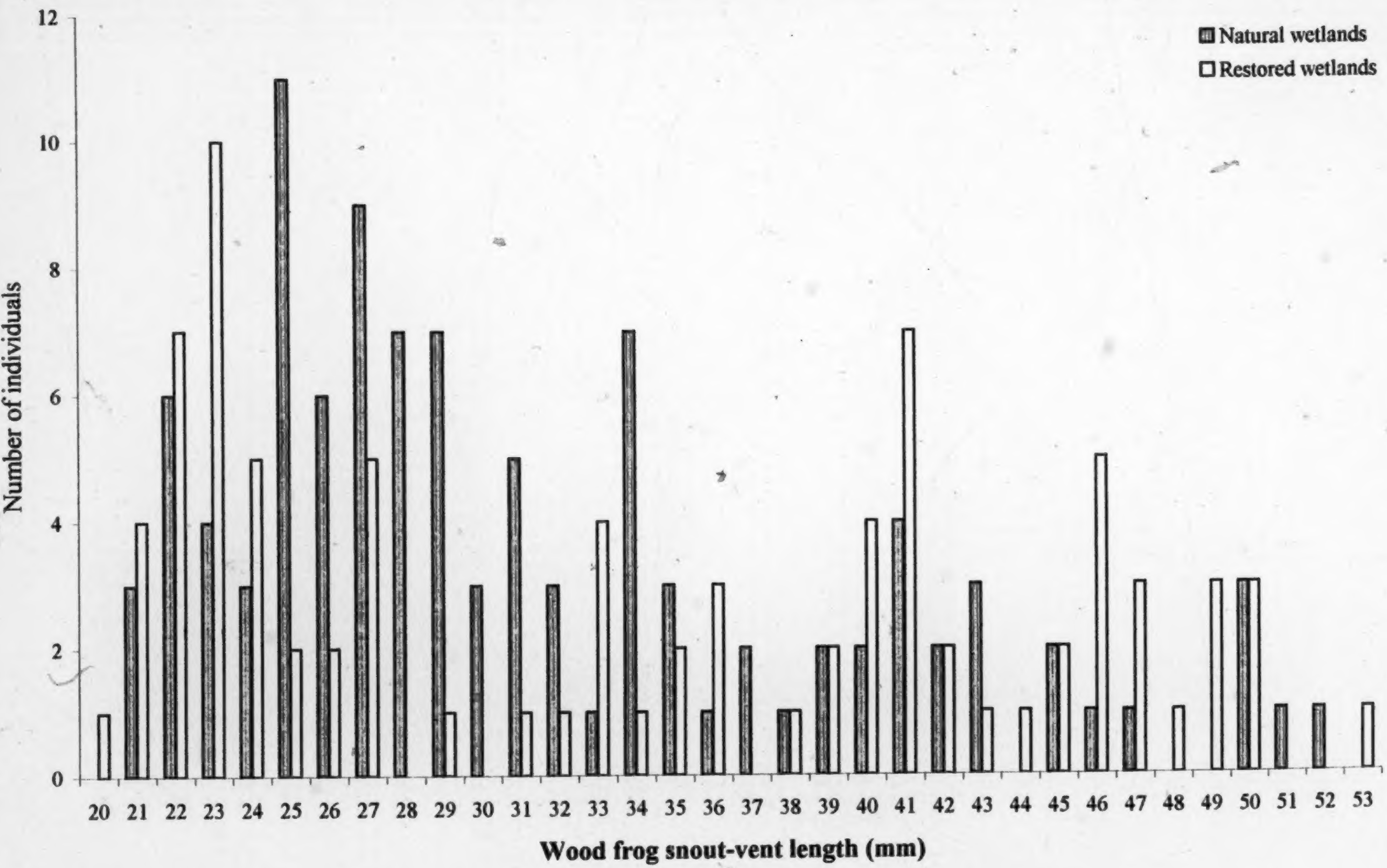
				Wood frog			Boreal chorus frog			Tiger salamander			
Project Name		Type	Status	adults	YOY	larvae	adults	YOY	larvae	adults	larvae	No. of PT nights	No. of MT nights
A&A Johnson A	*	IV	natural	27 (4)	3 (3)	27	0 (0)	0 (0)	0	12 (2)	0	448	152
Blue Sky A	*	IV	natural	15 (14)	4 (4)	44	0 (0)	0 (0)	0	14 (0)	15	348	156
Blue Sky B	*	III	natural	19 (2)	0 (0)	1	0 (0)	0 (0)	3	1 (0)	0	414	156
Hagstrom C		IV	natural	4 (1)	0 (0)	0	0 (0)	0 (0)	3	7 (4)	12	470	177
Lyseng 45 (A)		III	natural	24 (11)	18 (8)	242	0 (0)	1 (1)	1	6 (0)	0	439	177
			Subtotal	*89 (32)*	*25 (15)*	*314*	*0 0*	*1 (1)*	*7*	*40 (6)*	*27*	2119	818
A&A Johnson 6		III	restored	13 (4)	13 (12)	61	0 (0)	1 (1)	1	6 (4)	0	462	156
Beck-22	*	IV	restored	9 (4)	4 (3)	39	0 (0)	1 (1)	0	3 (0)	0	333	156
Coykendall 55	*	III	restored	12 (2)	1 (1)	0	1 (1)	0 (0)	0	2 (2)	0	522	52
Maruschak 12	*	IV	restored	24 (8)	4 (4)	28	3 (3)	0 (0)	7	0 (0)	0	290	177
Mittelstadt 2		IV	restored	11 (7)	7 (6)	102	6 (6)	0 (0)	9	0 (0)	0	386	177
			Subtotal	*69 (25)*	*29 (26)*	*230*	*10 (10)*	*2 (2)*	*17*	*11 (6)*	*0*	1993	718
TOTAL (Pitfall)				158 (57)	54 (41)	544	10 (10)	3 (3)	24	51 (12)	27	2119	818

Appendix 6: Summary of amphibian trapping data (pitfall and minnow traps combined (pitfall alone for adults and YOY)) for natural and restored wetlands near Foam Lake, Saskatchewan between May 21 and July 26, 2000. YOY = young-of-year, PT = pitfall trap, MT = minnow trap.

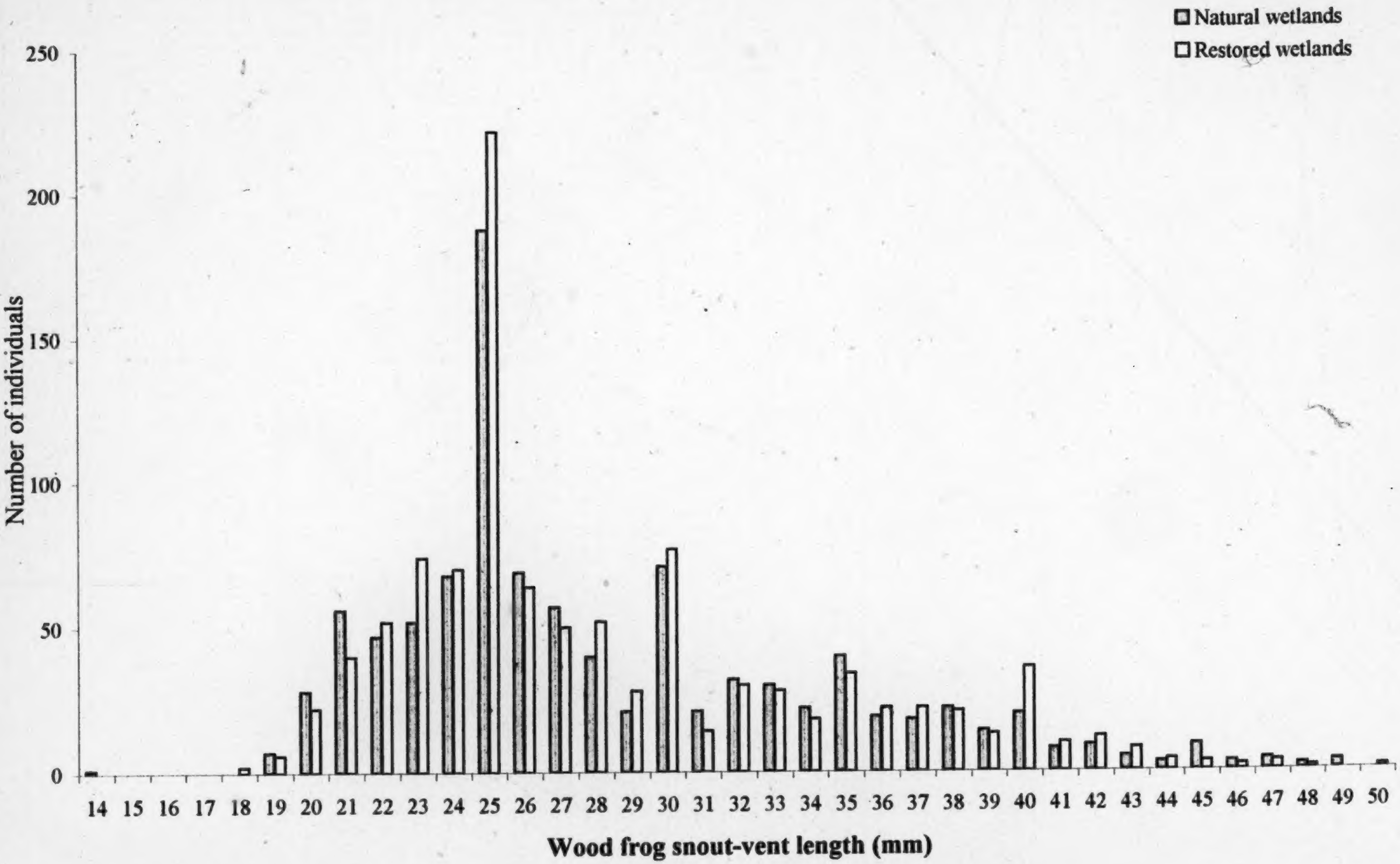
			Wood frogs			Boreal chorus frogs			Tiger salamanders			
Project Name	Type	Status	adults	YOY	larvae	adults	YOY	larvae	adults	larvae	No. of PT nights	No. of MT nights
Belitski A	IV	natural	25 (10)	19 (11)	105	2 (0)	0 (0)	0	6 (1)	2	456	208
Brezinski (Louis) E	IV	natural	86 (50)	35 (23)	184	0 (0)	1 (1)	13	2 (0)	0	487	220
Fullowka A	IV	natural	119 (40)	15 (15)	0	0 (0)	0 (0)	0	11 (4)	0	451	220
Hauers E	IV	natural	152 (83)	13 (10)	48	2 (2)	0 (0)	4	4 (0)	0	452	202
Koehl A	IV	natural	129 (65)	309 (291)	317	0 (0)	0 (0)	5	2 (1)	0	432	208
Shushetski A	IV	natural	391 (301)	80 (74)	17	0 (0)	0 (0)	0	1 (0)	0	470	211
		Subtotal	*902 (549)*	*471 (424)*	*671*	*4 (2)*	*1 (1)*	*22*	*26 (6)*	*2*	2748	1269
Belitski 08	IV	restored	60 (39)	6 (5)	8	0 (0)	0 (0)	2	0 (0)	0	465	208
Brezinski (Louis) 03	IV	restored	94 (59)	134 (105)	357	0 (0)	0 (0)	3	2 (0)	0	495	215
Brezinski 05	IV	restored	350 (245)	44 (35)	83	1 (1)	1 (1)	9	0 (0)	0	477	212
Gulka 01	IV	restored	114 (85)	44 (39)	268	0 (0)	0 (0)	4	2 (0)	0	477	211
Loshka 01	IV	restored	261 (153)	118 (114)	1174	0 (0)	2 (0)	11	35 (4)	0	477	212
Shewchuk 01	IV	restored	83 (56)	22 (14)	83	1 (1)	0 (0)	2	15 (0)	0	335	212
		Subtotal	*962 (637)*	*368 (312)*	*1973*	*2 (2)*	*3 (1)*	*31*	*54 (4)*	*0*	2726	1270
TOTAL (Pitfall)			1864 (1186)	839 (736)	2644	6 (4)	4 (2)	53	80 (10)	2	5474	2539



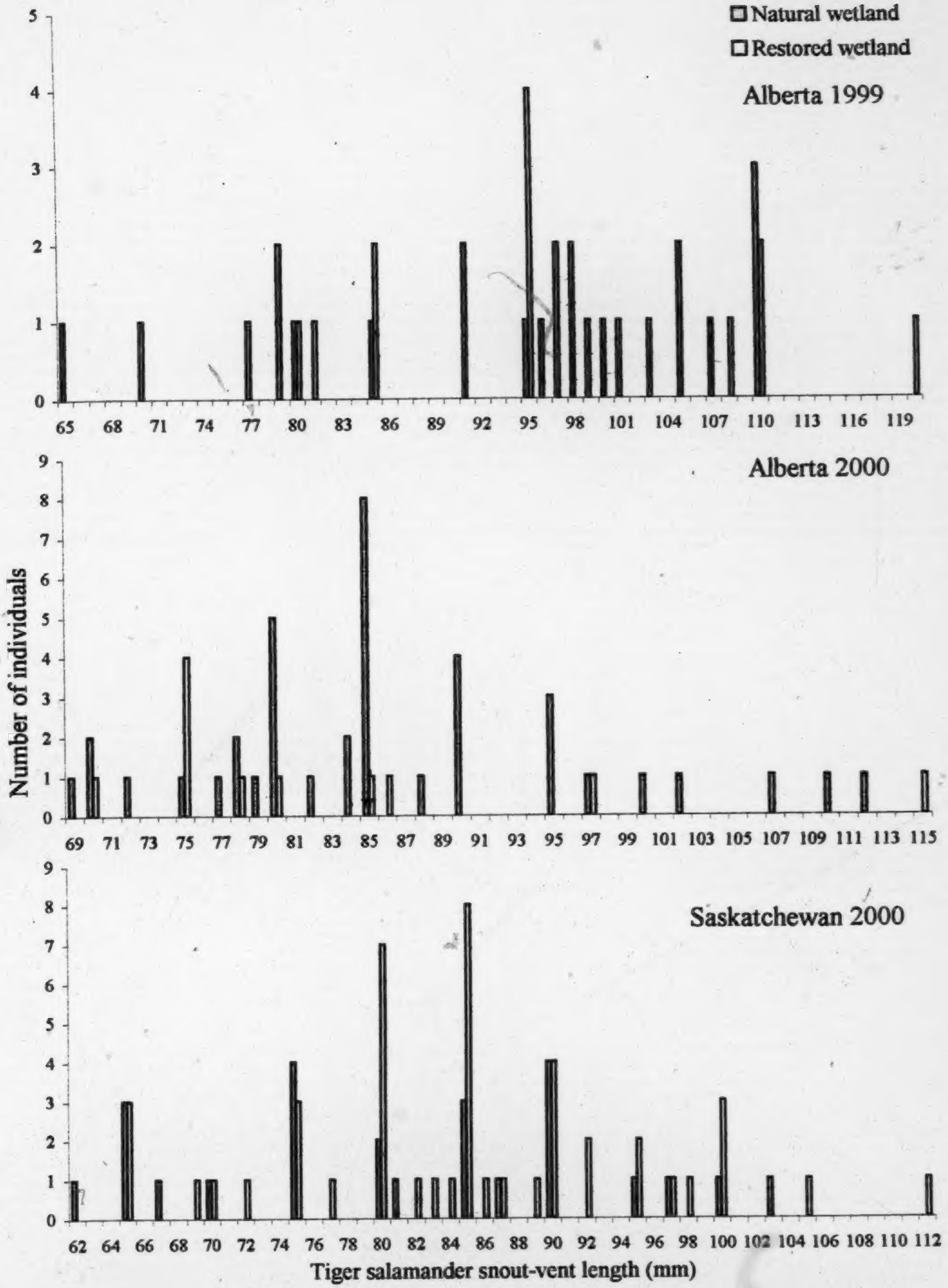
Appendix 7: Size-frequency distribution for adult and young-of-year (YOY) wood frogs captured in 7 natural and 7 restored prairie pothole wetlands near Camrose, Alberta between May 24, 1999 and August 4, 1999.



Appendix 8: Size-frequency distribution for adult and young-of-year (YOY) wood frogs captured in 5 natural and 5 restored prairie pothole wetlands near Camrose, Alberta between May 17, 2000 and July 29, 2000.



Appendix 9: Size-frequency distribution for adult and young-of-year (YOY) wood frogs captured in 6 natural and 6 restored prairie pothole wetlands near Foam Lake, Saskatchewan between May 21, 2000 and July 26, 2000.



Appendix 10: Size-frequency distribution for adult tiger salamanders captured in 14 (7 restored) PPR wetlands in Alberta 1999, 10 (5 restored) wetlands in Alberta 2000, and 12 (6 restored) wetlands in Saskatchewan, 2000.